BULLETIN 583 JULY, 1937

Codling Moth Biology and Control Investigations

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ACKNOWLEDGMENTS

The data used in this bulletin come from many sources. Much has been collected by the writer, but many other individuals have furnished invaluable information or have aided in the experimental work. J. S. Houser furnished biological data collected before 1923 and conducted field experiments at Marietta in 1926, 1927, and 1928. He has also given invaluable advice in the preparation of this bulletin. T. H. Parks has cooperated on many occasions, particularly in the biological work in Lawrence County and in furnishing many seasonal life history and control notes from other sections of the State. Harry F. Dietz, in charge of the Grasselli Fellowship at the Ohio Agricultural Experiment Station, together with his assistants, M. A. Vogel and A. H. Goddin, contributed in numerous ways, particularly from the control standpoint, during the course of this investigation. L. A. Stearns and R. B. Neiswander collected biological data in Lawrence County in 1928 and 1929. During the summers of 1931 and 1932 C. H. Huff was located in Lawrence County and furnished complete biological and meteorological data for these seasons. In 1934 M. A. Vogel conducted field experiments and biological investigations in the same county. Stanley Porter, Agricultural Extension Agent of Lawrence County, also has rendered valuable aid at many times. In Ottawa County, data concerning the control and biology of the codling moth have been taken in different seasons by Henry Miller, C. R. Neiswander, L. L. Huber, and Hugh Morrison. Mr. Morrison spent two full seasons in Ottawa County and his extensive notes are particularly valuable. During the summer months of the years during which this study has been conducted, the following entomological assistants have aided and greatly facilitated the work: Cleon Althaus, W. A. Goddin, Hugh Morrison, and Walter Fassig. To all of these men the writer expresses his sincere thanks.

CODLING MOTH[1] BIOLOGY AND CONTROL INVESTIGATIONS

C. R. CUTRIGHT[2]

INTRODUCTION

An accurate and complete knowledge of the biology of an insect is fundamental in its control. Hundreds of insect species are harmful to man and his property but not a single adequate control measure is used against any one of them that is not based on biological knowledge. In 1925, when increased codling moth damage was first noted in Ohio, it was determined that further biological studies were necessary and that these should be carried on over a period of years.

BIOLOGICAL KNOWLEDGE AS AN AID IN PRACTICAL CODLING MOTH CONTROL

A question that extension and research entomologists are frequently required to answer is, "If you tell me when to spray and with what to spray, why do I need any more information about codling moth?" In answer to this question it is proposed to summarize facts discovered by a study of codling moth biology and to show in each instance how a knowledge of these facts may be utilized by the orchardist in the control of this insect or how they have been utilized in the research program in perfecting methods of control.

Even a general knowledge of the biology of an insect renders possible the erection of certain safeguards against it. For example, if codling moth overwintered in the egg stage on the twigs of the apple tree, the basic ideas of control would be vastly different from what they are at present; or if the eggs were laid inside the fruit instead of on the surface of fruit or leaves, poison sprays might never have come into use. However, unless the complete biological truth is known, fragmentary information may be seriously misleading. The statement, "The codling moth overwinters on the trunks of apple trees", is true, but it is not the whole truth. If this were the only place the insect overwintered, the problem of control would be very much simplified.

Biological studies have shown that overwintering codling moth larvae are to be found in many other places besides the tree trunks. However, it will be shown in a later section that from 40 to 50 per cent of all larvae that leave the apples may be trapped under bands placed about the trunk. The fact that at least 40 per cent of a population can be concentrated under a band and destroyed at a later time has led to the development and introduction of poison, or self-working, bands. It is entirely reasonable to believe that the destruction of 40 per cent of the larvae will aid greatly in control, but without a study of biology this fact would never have been developed.

The first spray of the season in which a poison is used for codling moth control is the petal fall, despite the fact that eggs will not be hatching for about 3 weeks. This apparent waste of spray is justified by the biological knowledge that young larvae normally enter the fruit through the calyx and that the calyx cup can be filled with poison only at that time. Years of experience have justified this practice, which was first based solely on biological information.

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The next point at which thorough biological knowledge is essential is in timing the first cover spray so that it immediately precedes the hatching of the eggs. In order to do this, two things must be taken into consideration. First, the date of moth emergence must be known for that particular season, and, second, the evening temperatures following emergence must be kept in mind. The securing of adequate records of emergence will be discussed at length and the necessity for accuracy will be pointed out. The importance of evening temperatures was first recognized following the biological work of Isely and Ackerman in 1923[3], who showed that moths do not lay eggs when temperatures are below 62° F. In a practical way, this means that even though moths have emerged, spraying should be delayed until 5 to 6 days after a period of warm evening temperatures. This method of timing sprays applies especially to areas of moderate or light codling moth infestation, under which most of Ohio would be included. In some few, heavily infested Ohio orchards, where it is necessary to build up a load of spray on the fruit as soon as possible, timing is not so important because sprays are applied at regular intervals of from 10 days to 2 weeks after petal fall. Even in such cases, biological knowledge concerning the reactions of the young larvae on fruits covered with different amounts and kinds of spray is essential.

Cutright[4], having noted the greatly increased injury by codling moth during hot seasons, conducted laboratory experiments which showed that high temperatures also aided young larvae in entering the fruit. At first thought this may not seem a practical point, but after consideration, its application is clearly indicated. For example, in hot seasons, growers must definitely plan to apply one or more extra sprays to offset the temperature condition that promotes the welfare of the young worms.

Work with bait pails and light traps has aroused much interest because of the large numbers of moths so captured. However, in spite of the moths destroyed in this way, the records show that injury to fruit was not lessened materially. This is largely explicable by the biologic information that female moths deposit most of their eggs before they are attracted to the bait pails or light traps.

At the present time, orchard sanitation is widely urged as an aid in codling moth control. Sanitation includes such practices as (a) scraping the trees and burning the bark so removed; (b) removing by pruning enough wood so that all parts of the tree may be covered by spray; (c) prompt burning of prunings and other orchard debris; (d) destroying coarse weed crops in the orchard; (e) prompt disposing of wormy fruit; (f) screening or tightly closing packing house and handling crates in a sanitary way (that is, keeping them in tight storage till after emergence of moths or killing the larvae in them by heat or dipping); (g) encouraging birds in the orchard; and (h) thinning off and destroying injured fruit.

In reviewing the above-recommended practices, it is noted that practically all are based on biological information concerning the mature larvae and the places they utilize for cocooning. Such knowledge has been developed over a long period of years and though at many times it seemed of doubtful value, it has now been translated into the foregoing practical terms.

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[3]Isely, D. and A. J. Ackerman. 1923. Life history of the codling moth in Arkansas. Ark. Agr. Exp. Sta. Bull. 189.

[4]Cutright, C. R. 1931. Some laboratory reactions of young codling moth larvae. Jour. Econ. Ent. 24: 81.

REVIEW OF CODLING MOTH LIFE HISTORY

The general facts of codling moth life history are widely known, but in order to avoid any confusion they will be reviewed briefly.

In Figure 1 is presented a diagrammatic outline of codling moth life history during a normal year as it occurs at Wooster, Ohio. This is given primarily for the purpose of fixing in the reader's mind the dates or periods of time during which the different stages of the insect are living. It will be noted that there are one full brood and a partial second. The spring-brood moths come, of course, from larvae of both broods of the previous season that have overwintered.

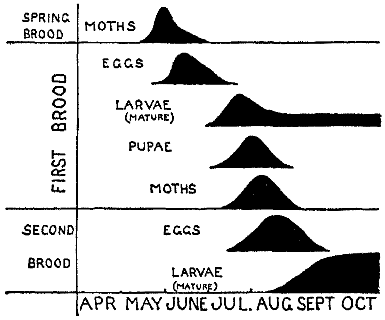

Fig. 1.—Diagrammatic outline of codling moth life history at Wooster, O.

The most common location of the overwintering larvae is under loose bark on the tree trunk and larger branches where they have spun their cocoons. However, worms can also be found in many other positions on the tree, such as rotten cavities and the splintered ends of broken branches. On the ground they can be located on any loose wood, old baskets, or old sacks, or in the stems of weeds. A very few go below ground level at the base of the tree or crawl into cracks in the ground, where they spend the winter. The mortality among such larvae is quite high, but those that survive emerge later than normal and thus prolong the spray season for the spring brood. Overwintering larvae may be found in other situations about the orchard, such as buildings or cracks in wooden fences. The packing shed is a favorite overwintering site for many larvae that leave the apples while the fruit is being packed. Moths coming from packing houses have a long-drawn-out emergence period, with the peak much later than normal. (See Fig. 2).

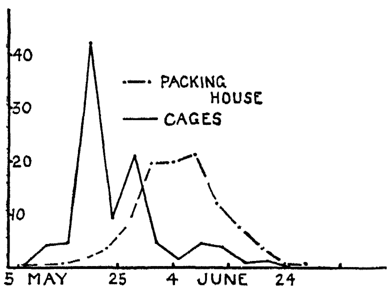

Fig. 2.—Emergence of spring-brood moths from cages (solid line) and from a packing house. Lawrence County, 1931. The late appearance of the bulk of moths is well illustrated by this typical curve.

Under outdoor conditions, the larvae remain inactive in their cocoons during the first warm days of spring, but usually in the latter part of April in northern Ohio the first individuals pupate. Temperature has considerable influence on the time and rate of pupation but it is not the only factor involved. For example, it is not known why larvae under the same temperature conditions pupate at different times, but this is the case. Frequently a period of over a month will elapse before all the larvae in a similar habitat pupate. Therefore, because of the different habitats of the larvae, 2 months may be required for all to become pupae. The length of the period spent in the pupal stage also depends, in part at least, on temperature and may vary from 10 to 20 days.

Before transforming to the pupal stage the larva cuts a circular opening in one end of the cocoon. This is not entirely severed but remains in place held by a small flap or a few silk threads. When the emergence time for the moth arrives, the pupa, by vigorously bending back and forth, thrusts itself through this opening to the outside. When the greater part of the pupa is free, movement stops and soon a slit appears along the back and across the head. Through this opening the moth emerges. From 10 to 30 minutes or more are required for emergence, after which the moth rests for some time, drying itself before flying away. The great majority of moths emerge during the hours from 8 to 11 A. M.

At Wooster, Ohio, moths have started emerging as early as May 5 and in one instance, as late as May 27. It has ended as early as June 14 and as late as July 6 at Wooster. Once under way, emergence continues from 6 weeks to 2 months. The average length of life of the free moth in the orchard is not known. Records of moths in captivity show that the average life span rarely exceeds 10 days, though there are many wide exceptions to this rule. Since moths in captivity show many abnormal traits, it is thought that free moths live considerably longer and that they lay more eggs.

In cages, if temperatures and other conditions are favorable, egg laying in greatest abundance usually occurs 3 or 4 nights after emergence. Egg deposition is greatly influenced by temperature; none occurs if the temperature is below 62° F. and only a small proportion, until 70° is reached. Above this point the number of eggs may be greatly increased. Also, if a moth lives during a period of high temperature, more eggs are deposited than if the weather is cool. Most eggs are laid during the twilight hours and some, just as day is breaking, although at daybreak low temperatures frequently interfere. In the orchard, the eggs are placed on the apples or on leaves close to the fruit.

Hatching takes place from 9 to 13 days after oviposition; the time is influenced largely by temperature. The younger larvae, if hatched from eggs on leaves, wander about until they encounter an apple, after which they soon attempt to "chew" into the fruit. Larvae from eggs on the fruits seldom leave the apple but usually attempt to enter after a short time. Not all larvae succeed in entering the apples, even on unsprayed trees. Considerable energy is required by the young worms to cut through the tough skin of the young fruit and if they have been weakened by much wandering or by cool weather before finding the fruit, many are unable to enter. Some die without leaving a mark on the apple; others break the skin, and this finally results in a sting. Early in the season the favorite point of entrance is through the calyx, but later many worms attack the sides or "cheeks" of the fruit.

Once inside, the larva usually bores directly to the center of the fruit, where it feeds on the seeds. The period spent in feeding and growth lasts from 16 to 25 days, depending on temperature. When nearly mature, the larva cuts a channel to the outside and leaves the fruit. If the apple is still on the tree the larva may drop to the ground by a silken thread or it may crawl on twigs and branches to the trunk. Many fall with the fruit to the ground. After leaving the apple, they, together with those that have dropped on threads, move about in ever-widening circles till they find the tree trunk or some other solid object that offers cocooning quarters. The position selected by all first-brood larvae for cocooning is similar to that of the overwintering larvae but the time spent in the cocoon at this season by those which give rise to the partial second brood is only 14 to 20 days. In northern Ohio, about half of the first-brood larvae, and particularly those which leave the apples during late July and August, do not transform to pupae but continue as larvae through the following winter.

Those first-brood larvae that pupate in midsummer go through a cycle much the same as already related, except that the higher temperatures of summer accelerate the development of all stages. The incubation period of the eggs and the resting period of the pupae are not so long, and the moths and larvae require a shorter period of time for their activities.

Figure 1 may be used also to represent codling moth life history in other sections of Ohio. In the southern part of the State the time period occupied by each stage is about 10 days earlier than shown. Also, in certain seasons, part of the second-brood larvae pupate and moths emerge, giving rise to a third brood of worms. In northwestern Ohio the time periods are from 4 to 6 days, and in northeastern Ohio, from 6 to 8 days later than the diagram indicates.

CODLING MOTH BIOLOGY AT WOOSTER, OHIO

Because the Agricultural Experiment Station is located at Wooster, Ohio, most of the work on codling moth biology in Ohio has been done at this place, although other records have been secured throughout the State whenever opportunity permitted. Wooster is located approximately 50 miles (map distance) south of Lake Erie and 80 miles west of the Pennsylvania-Ohio state line in latitude 40° 47′ north and longitude 81° 55′ west. The elevation is 1040 feet; the annual mean temperature for a period of 44 years is 49.3° F., and the average rainfall for 50 years is 38.94 inches.

The average date of the last killing frost in spring is May 9, and of the first killing frost in fall, October 7. The average growing season is 151 days.

Temperature and rainfall during the growing season for the past 11 years and evaporation during the past 9 years are shown in Tables 1, 2, and 3.

TABLE 1.—Mean Monthly Temperatures at Wooster*
1926-1936, inclusive

	Degrees Fahrenheit					
	April	May	June	July	Aug.	Sept.
1926	43.0	58.0	64.4	71.4	73.1	65.2
1927	49.1	59.0	62.8	71.0	65.6	66.0
1928	45.7	57.4	64.1	72.7	62.7	60.4
1929	51.7	57.7	66.0	71.6	66.4	64.8
1930	51.0	61.1	69.0	73.9	70.5	66.7
1931	48.4	57.4	67.7	75.6	71.8	58.4
1932	46.5	58.8	68.9	72.0	70.8	64.6
1933	50.6	61.8	72.4	73.8	70.6	67.2
1934	47.7	62.4	74.4	76.6	69.5	66.1
1935	45.4	54.2	65.3	74.8	72.0	62.2
1936	44.1	61.7	68.0	73.6	73.8	67.5
11-year mean	47.6	59.0	67.5	72.4	69.7	64.4
44-year mean	48.4	58.6	67.6	71.8	69.8	64.1

*Adapted from Bull. 544, Ohio Agr. Exp. Sta.

TABLE 2.—**Rainfall at Wooster***

1926-1936, inclusive

	Inches of rainfall						
	April	May	June	July	Aug.	Sept.	Total
1926	2.52	2.63	3.58	2.49	2.75	8.51	22.47
1927	3.02	4.45	3.36	4.28	2.88	2.62	20.61
1928	2.67	1.69	5.17	3.75	4.03	0.65	17.96
1929	5.58	4.84	4.10	6.79	1.26	1.66	24.23
1930	2.23	1.59	2.86	1.71	2.64	2.53	13.56
1931	4.10	4.45	3.49	2.97	4.68	3.48	23.17
1932	2.55	1.93	3.44	3.14	2.01	1.93	15.10
1933	3.47	4.77	1.67	1.73	3.85	4.23	19.72
1934	2.80	0.43	4.50	2.55	4.21	6.11	20.60
1935	1.01	4.17	4.88	9.30	9.53	1.96	30.85
1936	2.46	2.53	1.80	5.61	5.46	2.66	20.52
11-year mean	2.95	3.05	3.53	4.03	3.94	3.30	20.80
50-year mean	3.04	3.76	3.94	4.05	3.62	3.29	21.70

*Adapted from Bull. 544, Ohio Agr. Exp. Sta.

TABLE 3.—**Evaporation at Wooster, White Bulb Atmometers***

1928-1935, inclusive

	Cubic centimeters of water					
	May	June	July	Aug.	Sept.	Total
1928	1046	596	847	803	961	4253
1929	704	863	849	860	655	3931
1930	1093	1273	1442	1274	992	6074
1931	759	760	1100	924	706	4249
1932	885	1027	1131	1166	1014	5213
1933	719	1255	1396	1058	732	5160
1934	1406	1267	1102	923	664	5362
1935	790	890	843	690	704	3917
1936	972	1193	1284	939	851	5239
9-year mean	930	1014	1110	959	809	4922

*Adapted from Bull. 564, Ohio Agr. Exp. Sta.

As codling moth activities are closely correlated with weather conditions, these tables are included for reference.

Phenological data of certain types are of great importance in interpreting codling moth biology. Therefore, Table 4, in which are given the average dates of full bloom and first picking of fruit of some standard varieties of apples at Wooster, is included.

TABLE 4.—**Average Date of Full Bloom and Picking**

Average variety yield*

Variety	Average date of		Average yield, 20-year period starting at age of 17
	Full bloom	First picking	
			Bu.
Baldwin	May 6	October 16	15.2
Ben Davis	May 8	November 3	14.7
Grimes	May 6	October 2	20.4
Jonathan	May 7	October 8	11.1
Northern Spy	May 10	October 10	10.9
Rome	May 11	October 22	15.5

*Adapted from Bull. 472, Ohio Agr. Exp. Sta.

The average date of the earliest variety, Red Astrachan, to reach full bloom is May 4. The latest blooming variety is Ralls, which, on an average, attains full bloom on May 14.

SEASONAL LIFE HISTORY OF CODLING MOTH, WOOSTER, OHIO, 1926-1936

If each season brought the same problems in the same degree, the growing of apples or any other agricultural product would be greatly simplified. Problems of production, however, vary with the changing weather conditions of each season. This involves the grower in many new situations each year. The variation of the weather from normal is always reflected in some manner in the life cycle and activities of insects, and especially in the case of the codling moth. For the past 11 years annual records have been taken at Wooster in which complete data on certain phases of the codling moth cycle were secured. In the main, these data dealt with the chronological appearance each season of the pupae, moths, eggs, and larvae of the different broods. The duration of the stages, the peaks or periods of greatest abundance, and the time of last appearance were also recorded. From these data the graphs shown in Figures 3, 4, and 5 were compiled. Since space is limited, seasonal graphs for only two stages of the insect, the larva and the moth, are depicted.

Moth emergence records were secured from larvae collected under bands on orchard trees during the summer and fall months. As soon as the larvae were taken, they were permitted to spin up in strips of corrugated board and were then placed in screen cages of the general type shown in Figure 6. These cages usually were suspended from the lower branches of trees so that one side faced north and the other, south, with the corrugations containing larvae on both sides. Because of overhead branches the cage was in shade for at least a portion of each day. This gave an environment that corresponded roughly to a tree trunk. As the season for emergence approached, the cage was visited daily and when the first moths appeared, they were removed. This process was repeated each day as long as emergence continued. In making the graphs, total moth emergence for 4-day periods was used in order to obtain a more symmetrical curve. Otherwise, the curves appearing in the graphs are not smoothed.

Larval records were obtained by placing bands, usually of burlap-faced paper, around the scraped trunks of unsprayed apple trees. During the early part of the season these bands were inspected every 2 days and the larvae were removed and recorded. After the middle of August, the bands were usually "run" every 4 days. At the end of the 1936 season all records of moths and larvae were assembled, and the mean dates of first emergence, peak, and last appearance were computed. These three points were used as the base of an average curve that illustrates the typical life cycle of the codling moth at Wooster. In all graphs this average curve appears as the broken, dot-dash line. In the same space there appears the seasonal curve of codling moth activities, plotted in a solid black line, for any given year.

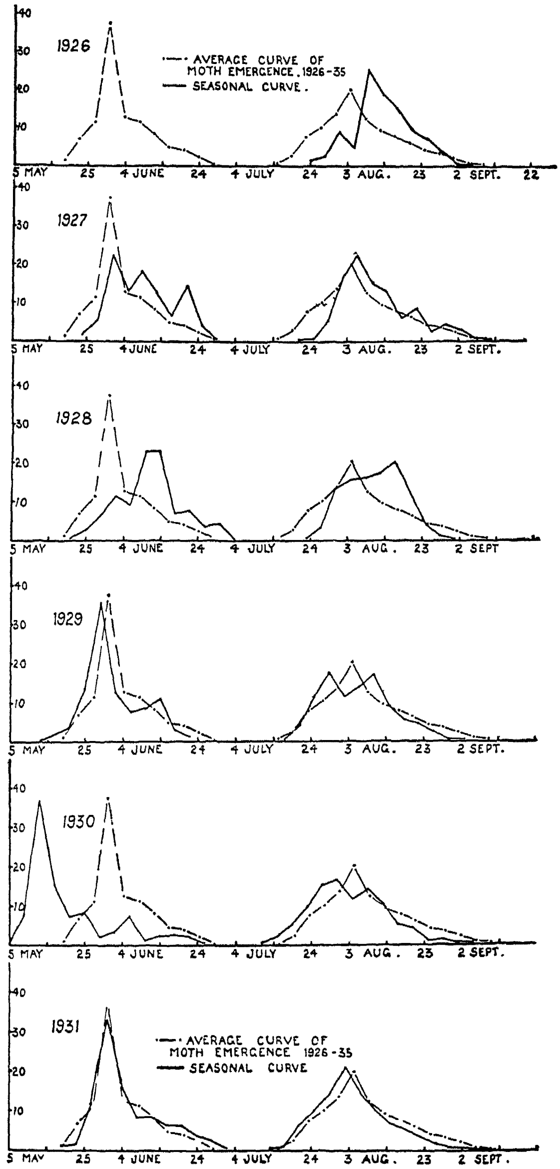

Fig. 3.—Emergence of moths of the spring and midsummer broods at Wooster, O., 1926-1931, inclusive. The broken line indicates the average curve for the 11-year period; the solid line, the curve for that particular season.

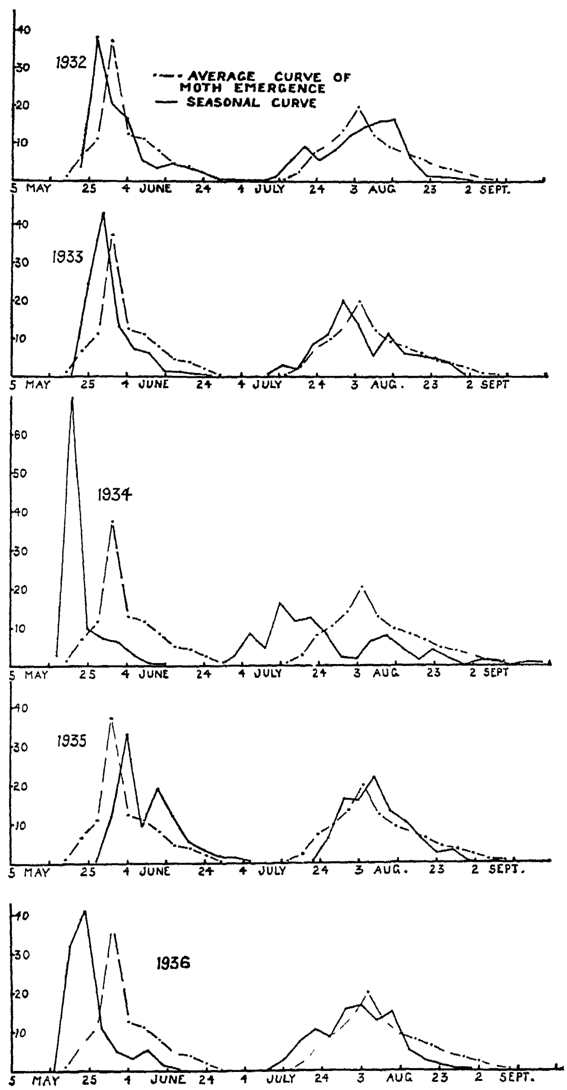

Fig. 4.—Emergence of moths of the spring and midsummer broods at Wooster, O., 1932-1936, inclusive

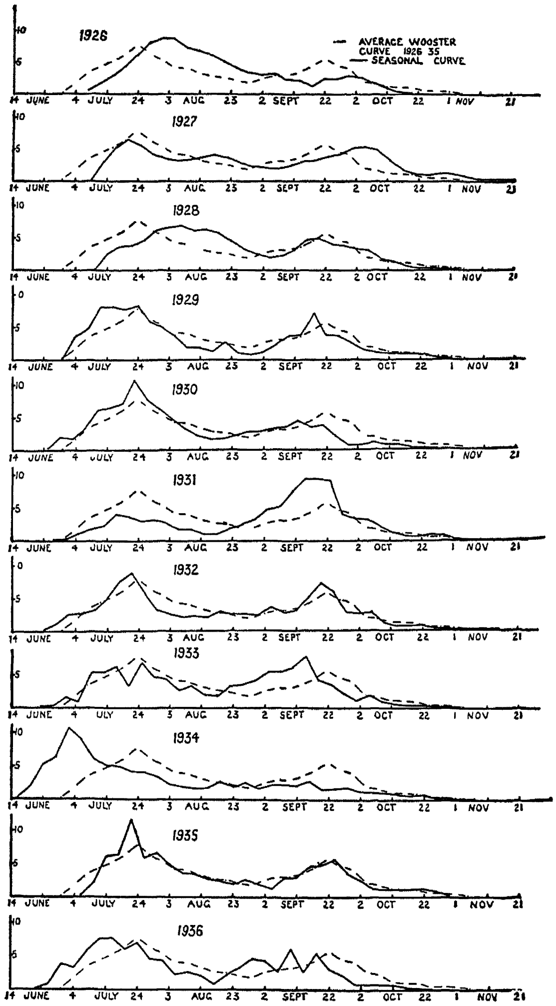

Fig. 5.—Mature codling moth larvae leaving apples, as indicated by catches under bands, 1926-1936, inclusive. The broken line indicates the average curve for the 11-year period; the solid line, the curve for a given season.

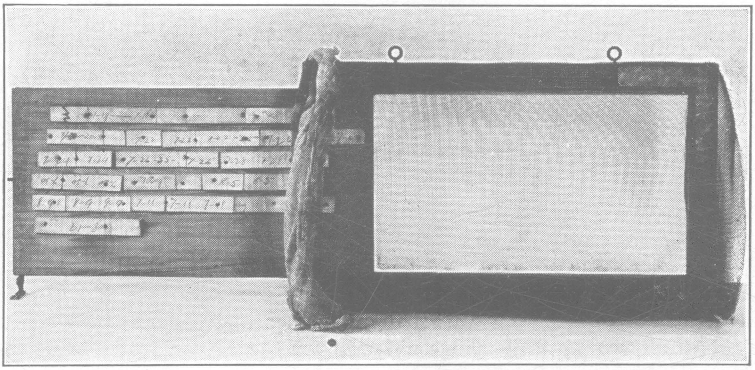

Fig. 6.—Cage for securing records of codling moth emergence. The board on which the corrugations are tacked may be slipped in or out of the cage.

1926

Spring-brood moths appeared later than average and this was reflected in a late peak for both first- and second-brood worms. Midsummer moths were late also, both in first appearance and in peak of abundance. Temperatures for this season were below normal for all months except August and September, and in the latter there was only a slight elevation. Codling moth was not difficult to control.

1927

A severe freeze during the last week of April seriously damaged fruit in central Ohio and practically destroyed the crop in the southern counties. Northern Ohio was not affected. Temperatures were below normal for June, July, and August. The first appearance of moths and larvae for all broods was later than normal and the same may be said for the periods of greatest abundance. Little difficulty was encountered in controlling the insect. Also, the crop loss in many orchards in southern Ohio greatly reduced the codling moth population although an open fall aided late worms in getting into hibernation.

1928

With the exception of July, monthly mean temperatures were below normal. A large crop was harvested in practically all commercial orchards. The first appearance and the peak of the different stages of both broods were in all cases later than the usual date. The insect was easily controlled.

1929

Early April temperatures were well above normal and this condition was reflected in southern Ohio by the earliest emergence and peak of spring-brood moths on record. In northern Ohio, however, April temperatures were not sufficiently high to offset the effect of a cool May and June. At Wooster, moth activities for all broods were nearly normal; whereas in northwestern Ohio they were generally late. July was about normal as to temperature, and August was below normal. At the end of the season, codling moth was at such a low ebb that Ohio entomologists considered abandoning research on the project.

1930

This was the first of the so-called drouth years in which temperatures were generally above normal and rainfall was deficient; in fact, the worst drouth of years was experienced. Temperatures were in excess of the average every month of the growing season. All stages of codling moth appeared earlier than usual and were so accelerated that by the latter part of the season larvae were present in such numbers that they not only caused a great deal of damage but also provided an overwintering population greatly in excess of normal.

1931

Codling moth activity during May and June was almost normal, but second-brood larvae appeared in great abundance and caused much damage to fruit. Rainfall was slightly above average for the growing season as a whole but was deficient in June and July. Temperature was about normal during April, May, and June but was far above the average in July and August.

1932

This was another season of deficient rainfall and excess temperature. The latter, however, was more nearly normal than in 1930. Excess temperatures were registered in every month except April. Spring-brood moths appeared slightly later than normal but emergence was so rapid that the peak was about 6 days earlier than usual. From this point on, all stages were slightly advanced. Codling moth damage was severe, especially in southern Ohio and along western Lake Erie. Poisoned bands were used in a few orchards for the first time.

1933

Rainfall for the growing season showed a deficit of about 2 inches and temperatures were greatly in excess of normal for the entire season. Codling moth appeared early, increased greatly during the summer, and was the worst problem of the year. A light crop in some orchards made the amount of injury especially noticeable.

1934

The season began with a cool April but this was followed by 3 very warm months. August was near normal and September was again above the average. Rainfall was almost normal and was well distributed except for a very dry May. Codling moth emergence started and peaked very early and larvae first appeared at the earliest date on record. There was heavy codling moth damage, especially in southern and northwestern Ohio. The highest percentage of injured fruit ever to be noted was observed in the horticultural orchards at Wooster.

1935

After five hot, dry seasons, 1935 reverted to the pattern of 1928. April, May, and June were much cooler than normal. Codling moth activity started slowly, with moths and other stages appearing from 7 to 10 days later than normal. Even the excess temperatures of July and August failed to bring the insect to a point where noticeable damage occurred. Although temperature conditions and codling moth injury were very similar to those of the season of

1928, there was a great difference in the amount of rainfall. Approximately 31 inches of rain fell during the growing season of 1935, mostly in July and August; whereas in 1928 there were only 18 inches.

1936

This season started with a very low codling moth population in all sections of the State. April was cool but the temperatures of May, June, and July were all above normal. Rainfall was generally deficient. Early first-brood larvae established themselves in considerable numbers and from these came a second brood large enough to cause increased injury. In general, the insect may be said to have staged a definite recovery with an increase in overwintering population large enough to menace the crop of 1937 if weather conditions favorable to the insect prevail.

CODLING MOTH BIOLOGY IN SOUTHERN OHIO, LAWRENCE COUNTY

Most of the work with codling moth in Lawrence County was done near Chesapeake and Proctorville. This general locality is near the southernmost point in Ohio in latitude 38° 40′ north and longitude 81° 45′ west. The elevation above sea level is approximately 550 feet. The average date of the last killing frost in spring is April 24, and the first in autumn is October 18. There is a growing season of 177 days. The mean annual temperature, based on a period of 46 years, is 54.6° F., and the average rainfall is 42.19 inches. The mean monthly temperatures for each month of the growing season are: April, 54°; May, 63.7°; June, 71.7°; July, 75.1°; August, 73.7°; and September, 67.9°. The average rainfall for the same months is: April, 3.45 inches; May, 3.58 inches; June, 4.29 inches; July, 4.29 inches; August, 3.84 inches; and September, 2.69 inches.

Before 1930 the codling moth problem in this area was not considered much more severe than that in other sections of the State. Stearns and Neiswander, while engaged in work with the Oriental fruit moth in 1927-1928 at Ironton, collected data dealing with codling moth life history. These are shown in Figures 7, 1928; 8, 1928; and 9, 1927-1928. From Stearns' report of these years it was evident that nothing of a particularly alarming nature was observed. In 1929, high temperatures in April got the moth off to an early start and despite a cool summer there was some increase. However, nothing abnormal was seen in the situation. In July, 1930, Parks noted increasing damage and stated that those orchards in which the 6-weeks spray had been omitted were much more severely injured. The situation increased in seriousness and by the end of the season hill orchards had lost a large part of their crop. There was definite indication of a partial third brood. On the other hand, orchards located in the main Ohio Valley did not suffer especially.

The losses of 1930 led the Extension Service to employ an entomologist for work in Lawrence County during 1931 and 1932. The Ohio Agricultural Experiment Station furnished equipment, and a cooperative biological study of the insect was conducted during the next 2 years. C. H. Huff, the field entomologist, not only collected records of the usual type but also made observations relative to the effects of temperature, humidity, and evaporation on codling moth activities in the two major habitats, namely, the hill orchards and the valley orchards.

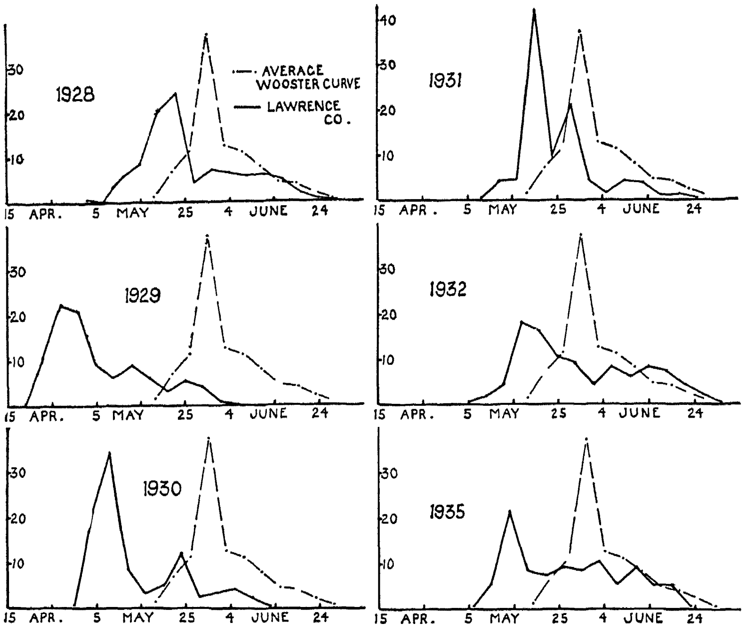

Fig. 7.—Emergence of spring-brood moths. Lawrence County, 1928, 1929, 1930, 1931, 1932, and 1935. The broken line indicates the average curve for Wooster, O.; the solid line, seasonal emergence in Lawrence County.

The records of larval appearance and abundance taken by Huff are not strictly comparable to Wooster records because Huff's data were all taken in sprayed orchards only. In our experience, codling moth activities in such orchards tend to be slightly delayed, and the curve is apt to be flattened. Despite these facts, Huff's records for the 2 years (Fig. 7, 8, and 9) show that moth appearance averaged from 10 to 14 days earlier than at Wooster and that other stages were correspondingly advanced. Huff's findings on this point are substantiated by other observations in the same area. In 1931 there was a partial third brood of larvae that caused severe damage. This occurred also in 1932, although the brood was not as large as that in 1931. In both years, lack of funds caused cessation of the work in early September; therefore, records on third-brood activities are not as complete as could be desired. The appearance of a third brood is not definitely recorded for 1933, but as injury was very severe, it is presumed that such a brood occurred. In 1934, M. A. Vogel reported a definite third brood with

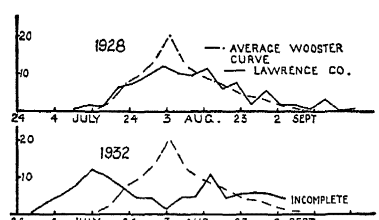

Fig. 8.—Midsummer-brood emergence of moths in Lawrence County, 1928-1932

severe injury on unprotected fruit. In 1935, no third brood was present and codling moth was not a serious problem at any time during the season. The following year, 1936, was started with a low initial population of worms, and in orchards where an adequate spray program was applied little injury occurred. On the other hand, orchards without a complete spray program were severely damaged because all weather conditions favored the insect.

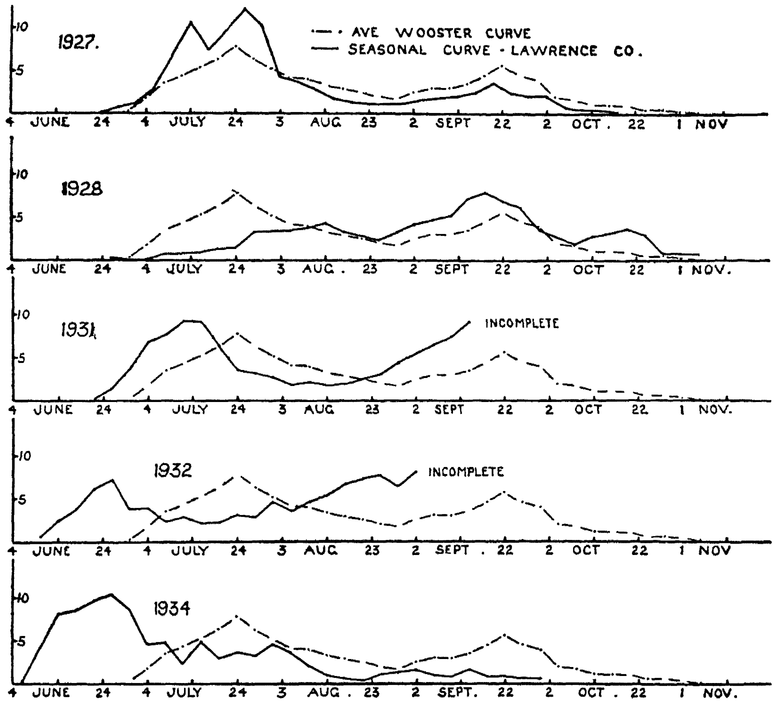

Fig. 9.—Mature codling moth larvae leaving apples, as indicated by catches under bands. Lawrence County, 1927, 1928, 1931, 1932, and 1934

In Lawrence County, the hill orchards are those lying on the tops of hills or ridges from 2 to 6 miles north of the Ohio River. The elevation ranges from 400 to 600 feet above the valley floor. Usually these orchards consist of a few rows of trees planted on the comparatively level crest of the ridge and other trees scattered on the slopes below them. The steep and rough character of the ground makes efficient spraying very difficult. In these orchards there is no permanent water supply and spray water is obtained from rain-filled holes dug in the clay of the hillsides. In very dry seasons, the water problem can be solved only by hauling from the Ohio River. The valley orchards are located on the valley floor of the Ohio River and its tributaries. They are level, easy to spray, and have an abundant water supply. In the cooperative experiment conducted by the Extension Service and the Experiment Station, Huff located hygrothermographs and atmometers in two hill orchards and two valley orchards. By a careful comparison of the records from the two situations it was hoped that differences in temperature, humidity, or rate of evaporation might be noted that would help explain the reason for severe codling moth injury on the hills as contrasted with slight damage in the valleys.

Huff found that temperatures in hill and valley orchards were almost identical and that hourly and daily temperatures showed no great variation. On the other hand, humidity and evaporation records varied widely in the two habitats. These results are shown graphically in Figure 10. In hill orchards, humidity was much lower throughout the season than in valley plantings, and the rate of evaporation was higher on the hill than in the low orchards.

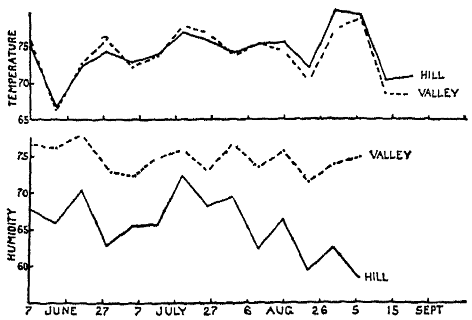

Fig. 10.—Comparison of temperatures and humidities occurring in hill and valley orchards of Lawrence County, O. Records by C. H. Huff, 1932

Since the foregoing conditions are fairly constant during the season of codling moth activity, the question arises whether or not they influence the varying amount of injury found in the different habitats. The fact that temperature above normal is highly favorable to codling moth has been shown definitely. However, when temperatures are equal, as in this case, there is the question whether low humidity or high evaporation accounts for the greater degree of injury that existed in the hill orchard. Hot seasons, which are favorable to codling moth, are usually dry; therefore, the accompanying decrease in humidity may be an added factor in increased injury by worms. In the Western United States where apples are grown in the arid valleys, codling moth is always severe and low humidity has been considered a cause for this condition. The 2 years' data from Lawrence County can well be interpreted as evidence in favor of this theory. The temperatures were similar, but there was far greater codling moth damage in the hill than in the valley orchards. However, such differences were not noted until 1930 and since the environmental factors must have been operative for years, there is the question of why this differentiation was not observed before. Because of the drouth in 1930, hill orchards were poorly sprayed or not sprayed at all in midsummer and, as a result, an enormous worm population developed. This was present to start the infestation of the next year and, in fact, for all seasons until 1936, since the insect was not greatly reduced till 1935. Could the greater amount of codling moth damage in hill orchards have been due to a much higher initial infestation coupled with poorer spraying rather than to lower humidity during the growing season?

Because of the foregoing, somewhat confusing factors, the data collected by Huff probably should not be considered as definite proof of the influence of low humidity in producing a severe codling moth infestation.

CODLING MOTH BIOLOGY IN NORTHWESTERN OHIO, OTTAWA COUNTY

Codling moth work in Ottawa County has been conducted mostly at Gypsum although several additional records were secured at Oak Harbor. Both these localities are near Lake Erie. Gypsum is located on the Danbury peninsula, 5 miles east of Port Clinton; and Oak Harbor is 10 miles west. Gypsum is in latitude 83° west and longitude 41° 45′ north. The elevation is approximately that of Lake Erie, 573 feet. The mean annual temperature is 51° F. and the average monthly temperatures for each month of the growing season are: April, 47.7°; May, 58.4°; June, 69.6°; July, 74.4°; August, 73.0°; and September, 66.1°. The annual rainfall averages 29 inches and is distributed during the growing season as follows: April, 2.85 inches; May, 2.57 inches; June, 3.16 inches; July, 2.26 inches; August, 2.80 inches; and September, 3.23 inches. The last killing frost comes about April 20 and the first frost in autumn averages October 28; this affords a long growing season of about 190 days. It will be noted that the spring months are cool and that the temperatures of July, August, and September are considerably higher than at Wooster. In general, extremes of temperature are not so marked as at Wooster and in Lawrence County.

Complaints of codling moth damage were heard from Ottawa County many years before the drouth period of 1930-1934. Damage in southern Ohio is usually attributed to the influence of high mean temperatures during the entire period of the growing season. In that part of the State, if the season is unusually hot, a third brood of larvae is produced. In Ottawa County, the cool, even temperatures of spring do not cause an early and rapid emergence of moths. Therefore, although the growing season is much longer, the season of moth activity is actually shorter than in Lawrence County or at Wooster. This usually eliminates the possibility of a third brood of worms. However, because the relatively higher temperature of July, August, and September favors the development of a particularly large and active second brood of larvae, the damage to thc crop may be unexpectedly severe. The attack occurs in late August and during September, and frequently extends into October.

Records taken during 6 different years (see Fig. 11) indicate that the average peak date of spring-brood emergence is June 17. Minor peaks of emergence frequently occur before this date (Fig. 11, 1927, 1930, and 1935) but the main peak is 17 days later than at Wooster and over 30 days later than in Lawrence County.

Since the bulk of spring-brood moths occurs so late, it follows that most eggs and larvae likewise are later. This condition is reflected during the warm months of July, August, and September in increased importance of second-brood larvae. The severity of attack by second-brood larvae is the characteristic feature of codling moth activity in this area. Despite this situation, our records show that actually a smaller proportion of first-brood larvae transforms to pupae and moths than at Wooster. That a relatively smaller number of moths produces a larger number of larvae is due to the warm temperatures of July, August, and September. The parent moths responsible for this destructive group of late-season larvae develop from the earliest individuals of the larvae of the first brood. Therefore, if the early worms of the first brood are controlled either by weather or by spraying, there will be such a small number of midsummer-brood moths that the usual severe fall damage is automatically eliminated.

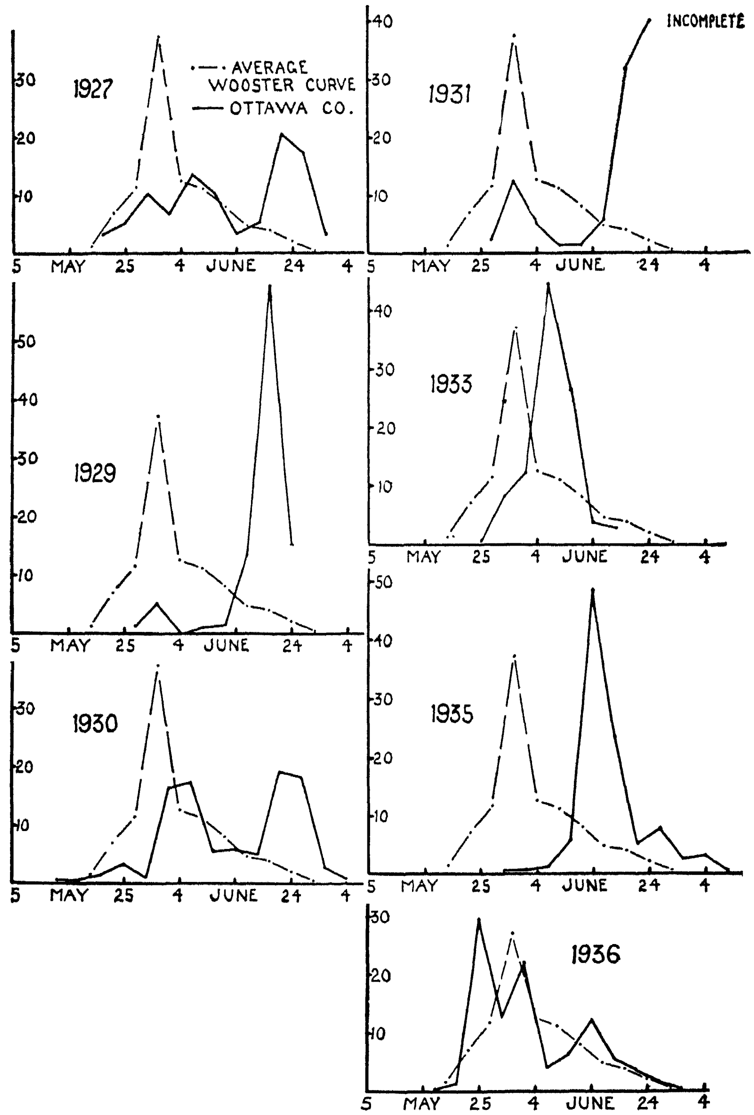

Fig. 11.—Emergence of spring-brood moths in Ottawa County. The broken line shows the average curve of emergence at Wooster; the solid line gives the seasonal emergence during different years in Ottawa County.

In the period from 1930 to 1934, with weather conditions during June favoring the insect and with spraying none too satisfactory, enough early larvae developed to produce moths in menacing numbers. From these came the larvae that so severely injured the crop from 1930 to 1934.

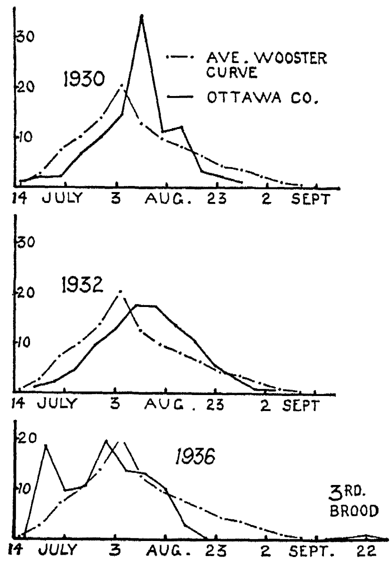

Fig. 12.—Midsummer emergence of codling moths. Ottawa County, 1930, 1932, and 1936

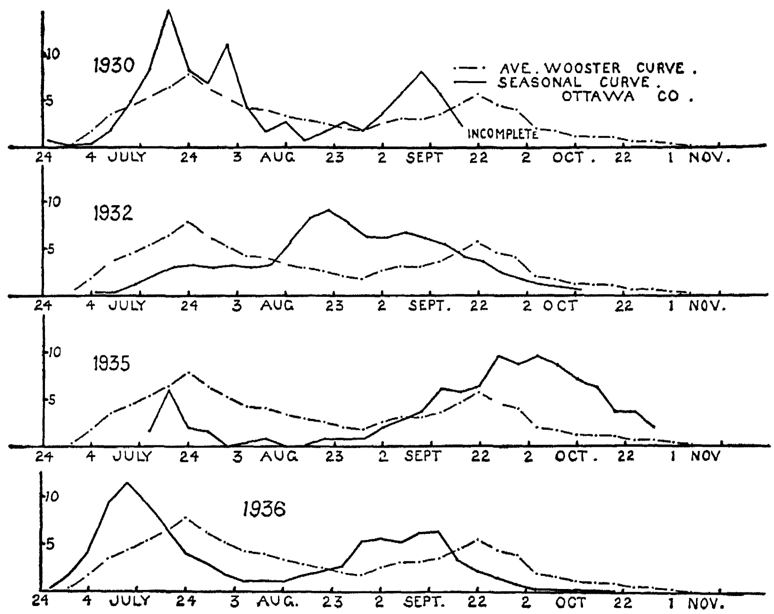

Fig. 13.—Mature codling moth larvae leaving apples, as indicated by catches under bands. Ottawa County, 1930, 1932, 1935, and 1936

In 1935, a combination of unfavorable early-season weather conditions and particularly effective spraying in June so changed the situation that relatively few early worms established themselves. In turn, second-brood moths were so scarce that late larvae were almost entirely absent.

The season of 1936 was in large part a replication of that of 1934. Codling moth populations again increased and damage to fruit was correspondingly severe.

THE CODLING MOTH AND THE WEATHER

Undoubtedly the reader has noted the many specific references to weather conditions as correlated with codling moth scarcity or abundance. During some seasons, favorable weather conditions so stimulated codling moth that the impetus given the insect more than overbalanced the degree of control exercised by the spray program. For example, in 1934, in both Ottawa and Lawrence Counties, a full schedule of sprays in many orchards failed completely to prevent damage to commercial crops. In 1935, however, even in poorly sprayed orchards, good control was obtained. The answer to this seeming paradox is that the weather of 1934 was favorable to the codling moth; whereas in 1935 the opposite condition prevailed.

Only the most technical research work will ever place the several weather factors in their exact positions as related to codling moth scarcity or abundance, and much of this work is yet to be done. On the other hand, a considerable volume of general facts has been collected and can be used to interpret certain codling moth phenomena.

TEMPERATURE

This factor is by far the most important. When temperatures are above average every phase of the codling moth life cycle is accelerated; consequently, in areas, such as southern Ohio, three broods may develop instead of two, or in the northern part of the State the second brood may be greatly enlarged. In either situation, the population is so increased that unusual damage will almost surely follow.

Not only are worms more numerous during abnormally warm seasons but moths lay more eggs than when temperatures are normal. In turn, a larger percentage of the eggs hatches and the resulting larvae are stronger and more active. Finally, such larvae are able to establish themselves in the fruit in greater numbers.

Recent work with young larvae under controlled temperature conditions conducted at the Ohio Agricultural Experiment Station revealed that as temperatures were increased from 60° to 85° F., injuries by young worms increased greatly, even on sprayed fruits. Just why lead arsenate is more effective at low temperatures has not been explained, but this work, as well as other supporting evidence, indicates that such is the case.

During the past 11 years a record of seasonal temperatures (see Fig. 14) and codling moth injury has been kept. A correlation of these records shows that in the seasons of 1926, 1927, 1928, 1929, and 1935, temperatures during the latter part of May and during the month of June were in all cases below normal. During these seasons codling moth was not difficult to control. On the other hand, temperatures above normal for late May and June existed during 1930, 1931, 1932, 1933, 1934, and 1936, and during these seasons codling moth was so

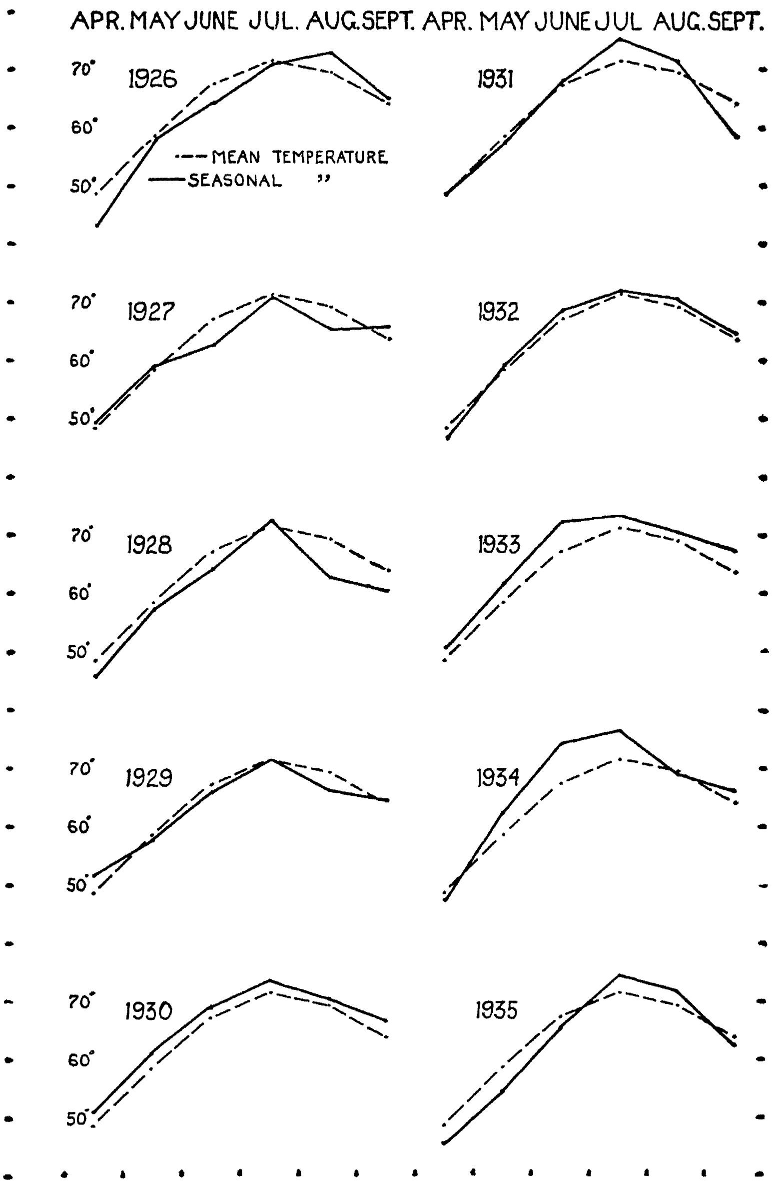

Fig. 14.—Seasonal monthly mean temperatures, 1926-1935, inclusive, as compared with mean temperatures established by records of over 40 years at Wooster, O.

severe that in many orchards satisfactory control was not accomplished. The same correlation has been demonstrated in Arkansas by Isely and Schwardt[5].

It is obvious that temperatures in the orchard cannot be controlled by artificial means, but specific advantage can be taken of the knowledge that increased abundance of codling moth is likely to develop during seasons when temperatures are abnormally high. For example, the intelligent orchardist, upon observing that a sustained period of abnormally high temperature is occurring, will apply one or more extra sprays to meet the situation. On the other hand, if temperatures are normal or subnormal and particularly if codling moth is well under control, an understanding of the codling moth – temperature relationship may obviate the expense and labor of one or more spray applications.

With the foregoing facts in mind, it is evident that a reliable thermometer and a precise daily record of the temperature are essential adjuncts to successful codling moth control. A maximum and minimum thermometer is of greater value for this purpose than an instrument of the ordinary type. For purposes of interpreting the meaning of the temperature records obtained, the orchardist should secure a set of the published records from his nearest Weather Bureau station. His own records may then be compared with the mean temperatures for that particular day, week, and month. This will give him some idea whether prevailing temperatures are high, normal, or low. After a few years he will have assembled a set of records which apply particularly to his own situation, and from these he can calculate the mean or average temperature for any particular period. This will be more useful for his needs than the records of the Weather Bureau station, which may have been taken under slightly different conditions from those prevailing in the orchard.

HUMIDITY

This has been fully discussed in the section dealing with codling moth biology in southern Ohio, and the reader is referred to that section.

RAINFALL

Ordinarily, it is considered that codling moth is most prevalent in "hot and dry" seasons. As has been indicated, the evidence points to the fact that as far as temperature is concerned, this is true. The data regarding dry seasons are not so definite because most years of abnormally high temperature are also years of drouth. It is difficult, therefore, to disassociate the influences of the two factors. However, certain definite exceptions to this general rule have been observed and these cast some doubt upon the statement that "dry weather is favorable to codling moth". For example, more rain fell during the growing season of 1931, which was a year of severe damage, than in the seasons of 1926, 1927, and 1928, during which time codling moth was easy to control. Also, 1934, another season of codling moth abundance, had more rain than 1928. Work at the University of Illinois by Shelford in 1927[6] indicates that rains occurring when the insect is in the pupal stage actually speed up the rate of development. Because of the foregoing evidence, the suspected influence of rainfall as a retarding factor in the biology of the codling moth may be questioned.

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[5]Isely, D. and H H. Schwardt. 1936. Variation in codling moth injury in Northwestern Arkansas. Jour. Econ. Ent. 29: 473.

[6]Shelford, V. E. 1927. An experimental investigation of the relations of the codling moth to weather and climate. Ill. Natural History Survey, Bull. XVI.

EVAPORATION

Of the 8 years in which evaporation records have been taken at Wooster, 5 have been favorable to codling moth and 3, unfavorable. In general, the seasons characterized by high evaporation were favorable, but in 1931, which was a favorable year, evaporation was lower than in 1928, when codling moth was easily controlled. Perhaps, if careful records of evaporation were taken over weekly instead of monthly periods of time a more definite correlation could be shown. The work in Lawrence County in 1931 and 1932 showed definitely that much more rapid evaporation occurred on the hills than in the valleys and that severe codling moth infestations occurred in the former locations. However, wind and low humidity on the hills both favor increased evaporation. As has been pointed out under the discussion on humidity, other factors must be considered before stating definitely that rapid evaporation is always to be correlated with severe codling moth damage.

SPECIAL PHASES OF CODLING MOTH BIOLOGY

During the course of this study the need arose for specific information concerning certain obscure or little understood phases of codling moth biology. Not only were the findings obtained of value in the planning of the research program from year to year but they were also of material aid in developing practical control measures. It is believed that a discussion of these special phases of the biology of the insect will serve a further useful purpose if made available to the grower. For this reason each of three special phases will be considered in some detail.

MOTH EMERGENCE FROM CAGES AS COMPARED WITH THAT FROM TREE TRUNKS

The object of taking an emergence record is to secure a sample that is representative of actual orchard emergence. It has been shown in an earlier paragraph that the correct timing of early-season codling moth sprays is dependent in part upon accurate knowledge of the time the first-brood moths are abroad. Further, it was explained how emergence cages had been utilized for this purpose. After several years' experience with cages of various types, field observations led us to believe that the time of codling moth emergence from cages differed in some respects from that of actual orchard conditions. An experiment was planned, therefore, to devise a method for securing an emergence record that would actually represent the behavior of the insect in the orchard proper.

The trunks of growing trees were selected and, without disturbing the natural condition of the bark, were enclosed by a wire screen (Fig. 15). Above the screen or at the point of branching, the trunk was surrounded by a tanglefoot band.

Commencing in mid-August and continuing throughout the remainder of the season, larvae taken at 2-day intervals from burlap-faced paper bands placed on other trees were liberated on the tree trunks under the wire screen, which protected them from birds and other predators. A record was kept of the number of larvae liberated on each tree. They were free to find their own cocooning quarters but were prevented from going above the cage by the band of tanglefoot. By crawling downward they could leave the trunk entirely, but indications are that less than 1 per cent did so. By placing a few larvae on the tree trunk at frequent intervals over a long period of time, a fairly large population was concentrated. The trunks of several trees were caged in the manner described.

Fig. 15.—A tree trunk used in securing records of actual orchard emergence. Larvae concentrated on the trunk are protected from birds by the wire screen.

In the spring, these tree trunks were inspected daily. Moth emergence was indicated by the protruding pupae cases, the tips of which remained attached to the cocoons. Such cases were removed daily and a record was kept of the number taken from each tree. At the end of the season, these data represented an accurate sample of emergence as it occurred in the orchard as a whole. Such records have been taken over a period of 5 years and are shown in Figure 16.

The data of 1934 are not included, for a faulty cage failed to keep birds away from the tree trunk. An inspection of Figure 16 shows that in 3 of 4 years, emergence on tree trunks started earlier than in cages and that in no instance did it start later; also, that tree-trunk emergence is more prolonged; that a larger proportion occurs in the latter part of the period; and that the sharp peaks of cage emergence are not present. However, the first peaks from the two types of emergence cages roughly coincide and, therefore, little change would be made in the date of the first recommended codling moth spray, no matter which type of cage was used.

TIME OF APPEARANCE OF INJURIES ON FRUITS

The discovery that seasonal codling moth emergence from the tree-trunk type of cage more nearly corresponds to that of the insect under natural orchard conditions than does emergence from any other type of cage known is further supported by a study of the time of appearance of injuries by codling moth on unsprayed apples. Work of this nature has been carried on over a 2-year period, and the results are shown in Figure 17. Two experiments were used in collecting these data. In the first, the entire crop on

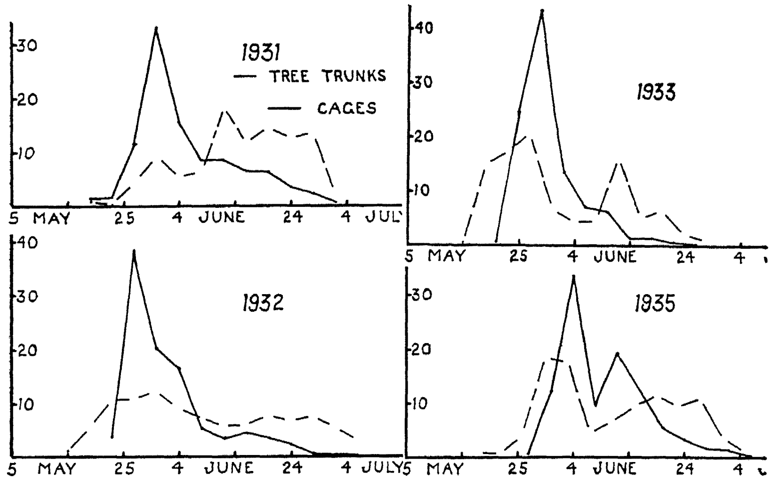

Fig. 16.—Emergence on tree trunks as compared with cage emergence. Broken lines indicate tree-trunk emergence; solid lines, cage emergence.

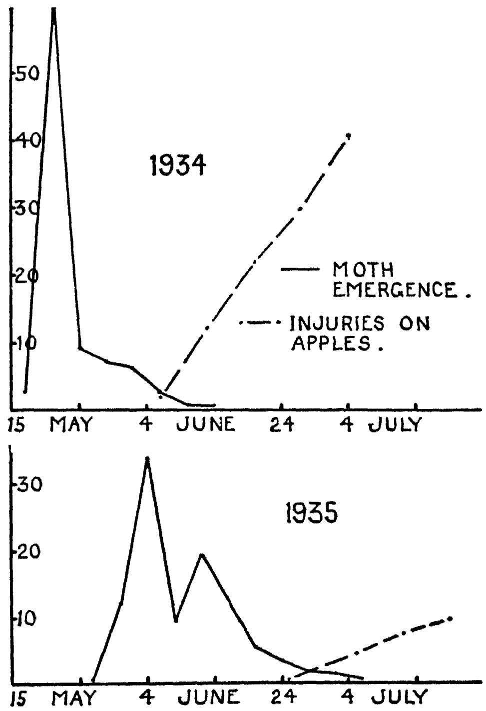

Fig. 17.—Time of appearance of injuries on apples in different seasons. Cage records of moth emergence for the seasons are also shown.

two small unsprayed apple trees was inspected as soon as any indication of injury by codling moth appeared in the orchard. All injured fruits were removed from the tree, and the type of injury was recorded. At the end of each successive week throughout the season the process was repeated, and in this manner the seasonal rate and time of appearance of injuries were determined. In the other experiment, a given number of fruits was examined when codling moth damage first appeared, and a record similar to the foregoing was made. In the second experiment, however, all fruits were left on the tree; hence, those damaged by the insect were possibly included in the record of succeeding weeks. The data produced by this method may be used in plotting a curve of seasonal cumulative injury.

The curve for the 1934 experiment indicates the earliness with which injuries appear and the rapidity of increase during a hot, dry season. On the other hand, the curve for 1935 demonstrates the retarded first appearance of codling moth injury and the slow rate at which injuries accumulate during a season of the opposite type.

SOME RELATIONSHIPS OF LARVA, FRUIT, AND TREE

From 1927 to 1931, inclusive, there was conducted each year at Wooster some work dealing with the relationships of larva, fruit, and tree. These experiments were not absolutely uniform from year to year, but in general the following plan was used. In mid-June of each year, trees bearing medium crops of apples in unsprayed orchards at Wooster were selected. No summer or early fall varieties were included. The selected trees would probably average from 25 to 30 years of age and were normal representatives of the semi-cared for orchard type.

After the trunk and larger branches had been carefully scraped, two bands of lightproof burlap were placed around the bole, one band near the ground and the other just below the point of branching. Usually, the two bands were 3 or 4 feet apart. A barrier of tree tanglefoot was carefully applied midway between the bands so that worms could not crawl the entire distance up or down the trunk without getting stuck in it. Therefore, all worms that were taken in the upper band must have crawled down the trunk and those found under the lower band must have come to the trunk from the ground.

Just beyond the tips of the branches and completely surrounding the tree, there was placed on the ground a barrier (Fig. 18) designed to trap all larvae wandering away from the tree. Such barriers were used during 3 years of the experiment.

The area beneath the tree was treated in different ways. In 1927, the ground under one tree was covered with a large sheet which fitted snugly at the base of the tree and extended to the barrier just beyond the spread of the branches. In other instances, all sod and litter were scraped away from the soil, leaving the bare, packed earth extending from the base of the tree to the barrier. Each year for a 5-year period, trees which received one or the other of the treatments just described were matched with other trees under which the sod or sod mulch was left undisturbed. The system of banding, explained in a previous paragraph, was identical for all trees.

The general purpose of this experiment was to determine what became of each codling moth larva produced on each tree. The investigators wished also to know whether the presence or absence of ground cover influenced the number of larvae that sought the tree trunk for cocooning purposes. It was essential, therefore, first of all, to record the type and extent of injury to the entire crop of each tree and, from these data, to calculate the number of worms which matured therefrom.

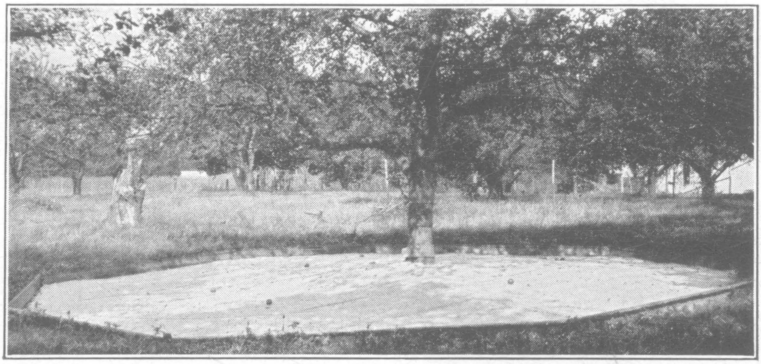

Fig. 18.—Special tree for larval relationship studies. The ground is covered by a sheet with a surrounding upright barrier, and bands of tanglefoot and burlap surround the tree trunk.

In order to accomplish this purpose, each year, as soon as the first evidence of injury was noted, trees were selected, and all dropped apples were collected and carefully examined externally and internally for codling moth injury. This procedure of collecting and examining "drops" was then continued, usually at 2-day intervals, throughout the season. At picking time, the fruit still remaining on the tree was gathered and examined in the same way. The upper and lower bands were also examined for larvae every 2 days and the barriers and other possible cocooning places, at longer intervals of time.

Thus, at the end of each season complete data could be assembled regarding the type of codling moth injuries on the fruit, the number and percentage of fruits free from injury, the number of mature larvae that left the fruit to seek cocooning quarters, and the number that were trapped in bands and barriers.

The summarized data from the 5 years during which the experiment was conducted are given in Table 5. From a study of these figures, many points, both interesting and practical, may be noted. Several of these will now be considered in detail.

PERCENTAGE OF MATURE WORMS THAT MAY BE CAPTURED UNDER BANDS

One of the main objects of the experiment was to secure data on this point.

In Table 5, column 5, is recorded the number of worms that matured on each tree each season and in columns 6 and 7 are the numbers and percentages that were trapped in the bands on the tree. Closely related to these figures are those in column 12, which show the percentages of maturing larvae that were not recovered. For the 5-year period the mean figures show that 28 per cent of the mature larvae was trapped in bands and that 64 per cent did not use them as cocooning quarters. The variation in numbers captured in different years is very great. For example, in 1930 only 17 out of each 100 mature

TABLE 5.—Complete Seasonal Data on Larval Populations of Codling Moth from Individual, Unsprayed Apple Trees

Year	Variety	Ground cover	Fruits, injuries, and larvae per tree						Percentages of mature larvae recovered						Percentages of different types of injuries to fruits			
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
			Total fruits	Injured fruits	% injured fruits	Worms per 100 fruits	Worms maturing	Trapped in bands	% trapped in bands	In upper band	In lower band	In barriers	All locations	Not recovered	Stings	Entrances	Larvae in fruit	Exit holes in fruits
1927	Baldwin..........	sheet	2628	1262	48	52	683	174	26	79	21	24	50	50	16	84	34	50
1927	Vandevere.......	sod	1947	1115	57	61	488	152	31	59	41	13	44	56	16	84	43	41
1928	Grimes..........	bare	1896	778	41	43	213	30	14	73	27	16	30	70	22	78	52	26
1928	Grimes...........	sod	2869	956	33	35	224	27	12	74	26	13	25	75	22	78	49	23
1929	Paradise Sweet...	bare	441	366	83	93	278	47	17	53	47	8	25	75	5	95	26	68
1929	Paradise Sweet..	sod	704	570	81	93	413	54	13	48	52	6	19	81	8	92	29	63
1930	Paradise Sweet...	sod	563	532	94	111	518	68	13	63	37	*	....	83	2	98	15	83
1930	Grimes...........	part sod	1252	746	59	64	532	42	8	71	29	....	....	92	12	88	22	67
1930	Rambo...........	sod	1362	961	70	72	811	230	28	46	54	....	....	72	12	88	5	83
1931	Baldwin..........	sod	3638	2753	76	83	1796	1238	69	24	76	....	....	31	13	87	27	60
1931	Northern Spy....	sod	776	678	87	97	538	400	74	32	68	....	....	26	13	87	16	71
								Mean	28	57	43	13	32	64	13	87	29	58

*No data. Barriers not used in 1930-1931.

larvae were trapped; whereas in 1931, 72 of every 100 were captured. This difference is thought to be due largely to a very heavy second brood of larvae in 1931, many of which reached the tree trunks in late season.

The small percentage of larvae captured under bands, however, may be quite misleading because we have no means of ascertaining exactly what percentage of those recorded as missing was destroyed by ants, birds, or other predators before they located cocooning places. Thus, it may be that many of them were destroyed and in this case the percentage trapped under bands should have been much higher. A general consensus of opinion among entomologists seems to be that about 50 per cent of all cocooning worms may be taken under bands. This being the case, growers should realize that bands are by no means a cure-all and that they should be used as a supplementary measure only when a fairly complete spray schedule does not control satisfactorily.

PERCENTAGES OF TRAPPED LARVAE IN UPPER AND LOWER BANDS

In columns 8 and 9 of Table 5 it will be noted that of all the larvae that sought the bands for cocooning purposes during the 5-year period, 57 per cent was in the upper band and 43 per cent, in the lower. This would indicate that a majority of mature larvae descended the tree trunk rather than crawled to the trunk from the ground. The figures show, however, that in some years, particularly those in which there was a heavy drop of infested fruit in late season, more larvae were captured in the lower band. This was especially noticeable in 1931. It will also be noticed that no barriers were used in 1930 and 1931 and that in these seasons there was a relatively higher percentage of larvae in the lower bands.

PERCENTAGE OF LARVAE FAILING TO ESTABLISH THEMSELVES ON UNSPRAYED FRUIT

It should be understood that many larvae which hatch on an unsprayed tree leave no record of their presence; others make "stings", thus indicating that they die long before maturity; and a third group feed and grow normally and finally leave the apple to find cocooning quarters. On the basis of laboratory experiments, it has been estimated that on unsprayed fruit, from 20 to 50 per cent of the larvae die before stinging or while attempting to enter the fruit. This varies a great deal in different seasons and on different varieties.

In column 13 of Table 5, the percentages of total codling moth injuries that finally resulted in stings are given. The average for the 5-year period was 13 per cent, and the number of larvae entering the fruit successfully was 87 per cent. These figures show that stings form a relatively small portion of the total injuries on unsprayed fruits but that such injuries occur. Their presence, therefore, can not always be explained by saying that "the young larva was killed by the poison spray as it entered the apple".

PERCENTAGE OF FRUIT-ATTACKING LARVAE THAT SUCCESSFULLY MATURE

Under the preceding heading it has been shown that an average of 87 per cent of all larvae attacking unsprayed fruit makes successful entry. From a study made while dissecting thousands of injured fruits and from the figures given in columns 15 and 16 of Table 5 it appears that after a successful entry has been made, the larva is likely to reach maturity. This possibility is greater if there is no more than one larva per apple. Where two or more worms are feeding in an apple at the same time there is likely to be some cannibalism. Also, a few die from disease. The condition of larvae found in the fruit (see column 15) indicates, moreover, that most of such worms would have finished feeding successfully and, therefore, eventually been recorded in column 16.

NUMBERS OF WORMS IN DROPPED FRUITS

A frequent question is, "Will the collection of drops and their removal from the orchard help in codling moth control?" From the data in column 16, Table 5, it appears that the answer is "No". When the drops were picked up at 2-day intervals, 58 per cent of the larvae had already matured and had left the apples. With so many worms already at large it is extremely doubtful if the number of larvae removed by collecting drops would pay for the labor involved. The longer the drops lie on the ground, the greater the likelihood that the worms will leave them.

The only occasion when drop collections may pay as a control measure is near harvest time when a heavy infestation is developing in late season. When drops are picked up at that time they should be disposed of promptly and not permitted to add to the infestation about the packing house.

INFLUENCE OF GROUND COVER ON ABILITY OF WORMS TO REACH THE TREE TRUNK

In 1927, 1928, and 1929 one tree each season had natural sod as a ground cover, and the other tree had either smooth, packed earth or, as in 1927, smooth earth covered by a sheet. The object of these different covers was to determine if one or the other aided the larvae in reaching the tree trunk. In column 12, Table 5, the figures of unrecovered larvae show that a higher percentage of larvae was recovered when the ground surface was smooth. A mean recovery of 35 per cent was made under the smooth-surfaced trees, and 29 per cent was recovered from the others. This difference is small and probably has no practical significance for the orchardist. Also, it will be noted that in 1931, when all trees had undisturbed sod mulch under them, the largest percentage of mature larvae succeeded in reaching the tree trunk. This, as well as wide variation in other seasons, led us to believe that the ability of larvae to gain the trunk is influenced to a large extent by the season.

VARIATIONS IN RATE OF INJURY DUE TO SEASON AND VARIETY

It is a well-known fact that the severity of codling moth attack varies from year to year. This is well illustrated by the data taken from unsprayed trees and is shown in columns 3 and 4 of Table 5.

The years 1930 and 1931 were both seasons of heavy codling moth damage and it will be noted that all varieties showed a higher rate of injury and more worms per 100 apples during this period. For example, compare Grimes in 1928 (41 and 30 per cent injured) with Grimes in 1930 (59 per cent injured) or Baldwin in 1927 with Baldwin in 1931.

Differences in susceptibility to codling moth attack can also be noted between varieties. In 1930 Paradise Sweet was injured 94 per cent; whereas Grimes in the same orchard had but 59 per cent of injured fruits.

EXPERIMENTS IN CODLING MOTH CONTROL

SPRAYING

Since the introduction of spraying as a means of controlling codling moth, this method has been proved far more effective and economical than any other measure. It is, therefore, only logical that spraying should receive much attention in an experimental program.

In 1926 it was decided that improvements in spraying might possibly be made: first, in the technique of spray application; second, in the more perfect timing of sprays; third, in the amounts of materials used; fourth, in the addition of spreading and sticking agents; and fifth, and most important, in the finding of new and more effective spray materials and spray combinations. With the arrival of the spray residue problem, the search has been modified to include only those materials whose residues are harmless or can be removed easily.

EXPERIMENTS IN METHODS OF SPRAY APPLICATION

The necessity of covering the trees with spray as rapidly as possible first led to the practice of the operator's riding a continually moving sprayer through the orchard. As pumps, guns, and spray-brooms of greater capacity appeared, the speed of the moving sprayer was similarly increased until some spraying performances came to resemble closely speed events. Despite the great capacity of the equipment, the tree was passed by so quickly that it did not receive enough spray and that what it did receive was not properly distributed. Observations and experiments of many seasons show that better tree coverage is always obtained when the sprayer stops for each tree. However, when the acreage to be covered necessitates a constantly moving sprayer, two spraymen should be used. The one who sprays the top of the tree should be located on a tower; the other, who sprays the lower branches, on a low platform. The volume of discharge and the speed of the moving sprayer must be such that each operator has an opportunity to cover thoroughly those portions of the tree assigned to him. Too frequently the inner portions of the tree are seriously neglected. In fact, the likelihood of inadequately covering the inside of the tree is the greatest disadvantage of the constantly moving sprayer.

In 1928 at Delaware, Ohio, and in 1930 and 1931 at Gypsum, Ohio, experiments were conducted in which trees sprayed from the outside only were compared with trees sprayed from both the outside and inside. The inside spraying of the trees was done by a sprayman who walked under the branches and thoroughly sprayed all under surfaces. The result of spraying both inside and out was a marked improvement in codling moth control over spraying from the outside only. In view of these experiments, this system has been adopted for all codling moth field tests even though a fewer number of trees can be sprayed per hour. Some practical orchardists whose acreages are not too large have also adopted this practice with favorable results, when expressed in terms of codling moth control.

Because wind is sometimes a problem in spraying, orchardists frequently inquire if the codling moth can be controlled effectively by "spraying with the wind". This system consists of spraying one side of the tree with the wind and then waiting till the wind direction reverses or changes before spraying the other side. It is generally considered to be more economical in the use of spray materials and is undoubtedly far more comfortable for workmen than spraying into the wind half the time. In conducting plot work it is the usual practice to spray each tree completely before passing to the next. Since many different materials and combinations are used in an experimental plot layout, spraying twice on one plot in order to spray with the wind would lead to a great deal of confusion. In commercial orcharding, however, it is the usual practice to cover the entire orchard with the same spray material; so there is no reason for confusion. From observations and experiments by the writer it would seem that codling moth can be controlled successfully by spraying with the wind if precautions are taken in the following matters:

(a) It may be absolutely essential that all trees be completely covered within a 4- or 5-day period. Therefore, if the wind has not changed in time to accomplish this, the trees must be completed by spraying into the wind even though the cost in materials and comfort is high.

(b) Spraymen must be specially trained to leave no unsprayed spots on the tree. Frequently, after the wind changes and when the tree is being completed, the two sprayings will not overlap and an unprotected area is left which later proves a starting point for worm activities.

TIMING OF SPRAYS

Experiments in the timing of sprays have been conducted in two ways. First, one or more sprays have been dropped from the regular schedule and the results of such omissions later noted by comparing the fruit with that from plots receiving a full spray schedule. For example, in 1927 at Delaware, Ohio, one plot was left without lead arsenate in the calyx. In other years and in different places various cover sprays or the last spray of the year has been dropped. To give in detail the results of these omissions would require a great deal of space; to avoid this, the findings will be summarized. In brief, these are: (a) The calyx spray should never be omitted in Ohio, as it is of prime importance for the control of codling moth, as well as for plum curculio attacking apple. (b) When six or more cover sprays are applied, the omission of one will not be greatly noticed. However, the fewer the number of cover sprays, the greater the seriousness of dropping any one of them. (c) In seasons when the first brood has been controlled and no more than ½ per cent of wormy fruit is noted by mid-July, further spraying may be suspended without commercial damage.

The second method of improving timing of codling moth sprays is that of correlating the activities of the insect, particularly those of egg laying and hatching, with the effects of sprays applied before or during such periods. Such correlations have been made every season since 1926. In this manner it has been determined that an application of spray is far more effective if put on 2 or 3 days too early than if put on 2 or 3 days too late. This has been demonstrated in commercial orchards, as well as in experimental plots. It was particularly obvious in 1934 and to a lesser degree, in 1936.

In those sections of the State where no more than three cover sprays are applied for the season, correct timing is necessary for the economical and effective use of spray. Therefore, all growers who use short schedules are urged to pay close attention to this factor either by following the Extension Spray Service recommendations or by relying upon emergence cages or bait pails of their own. When the schedule is lengthened to include six or more covers the first one against each brood is timed and the following sprays are applied at more or less regular intervals (10 days or 2 weeks), according to the total number planned for that particular brood.

CHANGING THE AMOUNTS OF MATERIALS USED IN SPRAYING

When experiments in the control of codling moth were started in 1926 the recommended amount of lead arsenate was 2½ pounds per 100 gallons of spray. Liquid lime-sulfur was used at 1 to 40 and dry lime-sulfur and Bordeaux were applied at dosages considerably higher than those used at present. The practice of adding excess amounts of lime to the spray was only beginning. As codling moth was on the increase, one of the first experiments dealt with the possibility of increasing the lead arsenate content of the formula. This experiment was conducted at Delaware, Ohio, in 1927 and 1928 on the property of the Delaware Orchard Company. Plots of Rome trees were sprayed with lead arsenate at 2½ pounds, 3 pounds, 3½ pounds, and 5 pounds per 100 gallons of spray. The larger amounts generally increased the efficiency of the spray but the gain made by using 5 pounds in place of 3 or 3½ pounds was not great. The gain made by using 3 or 3½ pounds instead of 2½ pounds was considerable and present-day recommendations are based largely on these findings.

The question of the effect on codling moth control of adding lime to lead arsenate – lime-sulfur sprays was answered by experiments conducted at Gypsum, Ohio, during the period from 1930 to 1932, inclusive. It was shown that increasing the amount of lime decreased the efficiency of the lead arsenate against codling moth in proportion to the amount of lime added. Some lime should be used to decrease burning and russeting by the spray but this should not exceed the amount recommended in the regular spray calendar.

Also, the question was raised concerning the comparative effectiveness in codling moth sprays of lead arsenate combined with dry lime-sulfur or with liquid lime-sulfur. These combinations were tested at Gypsum in 1931 and 1932 but results showed little difference from the use of either combination.

INCREASING THE EFFECTIVENESS OF LEAD ARSENATE BY THE USE OF SPREADING AND STICKING AGENTS

Many materials have been used by other experimenters in an endeavor to increase the spreading and sticking properties of lead arsenate. It was hoped by this procedure to make it more effective in insect control. The first work of this nature against codling moth in Ohio was conducted at Delaware in 1927 and 1928, when lead arsenate was used both with and without calcium caseinate. The results of the 2 years' work showed little or no advantage as far as codling moth control was concerned. Sprays in which the spreader was incorporated gave a smooth, even coverage on the foliage but this seemed to be the only advantage.

Spreaders may be incorporated directly with the lead arsenate during the manufacturing process. Such a material (NuRexform Lead Arsenate) was tested in comparison with a standard lead arsenate at Delaware in 1927 and 1928 to determine if the processed material gave increased codling moth control. In each of the 2 years no differences in control were noted between the two materials.

In 1930 and 1931 at Gypsum, Ohio, the commercial spreader known at that time as Fluxit was used with lead arsenate. Only three cover sprays were applied for the season. Where Fluxit was added to lead arsenate – lime-sulfur, a very even coating of spray was obtained but evidently this was not heavy enough to afford protection, because fruit on all plots so sprayed was more severely injured by codling moth than that on plots where lead arsenate was used alone. In 1935 and 1936, however, when Fluxit of a somewhat different character was used with lead arsenate in a schedule consisting of five cover sprays, better control was secured. This was due, of course, to the protection of the heavy film cover that five sprays built up.

Fish oil has been used successfully as a sticker in the East, particularly in Delaware. It was tried at Wooster and Gypsum, Ohio, in 1931 and 1932. Better codling moth control was obtained when it was added to lead arsenate but the difference was not great. Also, increased russeting was noted on fruits to which it had been applied. Apparently, Ohio conditions are not favorable to the use of fish oil.

Soluble fish oil (National Oil Products Co.) was used in tests in 1936. The results showed decreased codling moth injury on plots where this material was added to lead arsenate. There was no burning or russeting but the difference in its favor was not great and, therefore, was of doubtful significance. However, it seemed to be well worthy of future trial. It cannot be used with lime-sulfur.

Soybean oil was tested as a sticker in 1932 and 1933. It increased the efficiency of lead arsenate in all tests. The objections to its use were that some russeting occurred on susceptible varieties and that it built up a heavy deposit of spray residue which was difficult to remove from the fruit. For these reasons soybean oil has not been recommended. In the foregoing experiments, the oil was used at the rate of 1 quart per 100 gallons of spray. It now appears that one-half this amount would have been sufficient.

Other soybean products are used as stickers. Among the most successful is soybean flour (5 per cent residual oil). This material, when used in 1936 at the rate of 1 pound per 100 gallons of spray, markedly increased the effectiveness of the application and at the same time left a residue that was easy to remove in the usual acid bath.

Waste sulfite liquor and Goulac, its dry form, were tested as stickers for lead arsenate in 1931 and 1932. These tests gave some evidence of increased control but the increases could not be proved significant, and, therefore, the materials were never recommended.

Among the spreaders which have been tried within recent years is a sulfated alcohol composition known as Grasselli Spreader (SS-3). When used in small quantities (1 ounce per 100 gallons of spray) it produces an even covering on the fruit. Combined with lead arsenate, it has improved the control of codling moth.

Highly refined mineral oil was first used with lead arsenate in 1928 at Delaware, Ohio. Plots so sprayed produced 2.5 per cent of wormy fruit; whereas 8.5 per cent of the fruit was wormy where lead arsenate alone was used. Almost every season since that time some work has been done with oils as stickers and in every case a marked increase in control has resulted.

Several problems are encountered with the oil-lead arsenate combination. First, if oil is included in the entire cover-spray schedule, excess residues will be found at harvest time and a washing program will be required. Second, a suitable fungicide for use with the oil-lead combination has not been found. The latter difficulty may be largely overcome by thorough spraying in the early part of the season, in order to have scab under control when the time arrives for the use of oil in the schedule. When oil is used too soon after an application of lime-sulfur, burning of foliage may result; therefore, it is recommended that at least 2 weeks elapse after a lime-sulfur application before oil is used in a spray. If lime-sulfur is used in the calyx application, and this is necessary in Ohio, the next spray should be one of lime and lead arsenate. Following this, the next spray may contain oil. Such a schedule has been used successfully on scab-resistant varieties, such as Jonathan, Grimes, and Baldwin, and on the other more susceptible varieties where thorough early spraying had controlled disease.

To summarize the experiments with spreaders and stickers for lead arsenate, it may be said that there are many materials that will perform the function of stickers. All of them, if used in several applications, will build up spray residues beyond the tolerance. At the present time mineral oil is the preferred sticker, especially where diseases are under control. It is most effective in increasing the efficiency of lead arsenate. Where a fungicide must be used, soybean flour is preferred, with Grasselli Spreader (SS-3) a close second.

As an example of the type of work done with spreaders and stickers, there are presented in Table 6 the results of a series of experiments conducted at Gypsum, Ohio, in 1936. Each figure is a summarization of the results from eight replicated one-tree plots. The schedule consisted of a calyx and five cover sprays, the last of which was applied on July 27.

TABLE 6.—Spreader and Sticker Experiments, Gypsum, Ohio, 1936

Materials	No. of fruits	Worms per 100 apples	Lead residue*
Lead arsenate .... 3 lb.	12,887	10	0.038
Lead arsenate .... 3 lb. Grasselli Spreader (SS-3) .... 1 oz.	13,491	7	0.048
Lead arsenate .... 3 lb. Soybean flour .... 1 lb.	8,353	6	0.057
Lead arsenate .... 3 lb. Ortho Dry Spreader .... 4 oz.	8,788	9	0.039
Lead arsenate .... 3 lb. Ortho-K Oil .... ¾ gal.	15,994	3	0.060
Lead arsenate .... 3 lb. Soluble fish oil .... 1 pt.	13,644	7	0.050

*Grains per pound of fruit.

EXPERIMENTS WITH MATERIALS OTHER THAN LEAD ARSENATE FOR CODLING MOTH CONTROL

Lead arsenate has been the standard poison used in codling moth control for many years. Since there are thousands of other chemicals, it is only reasonable to suppose that some of them might control codling moth more effectively than lead arsenate. Materials for field experiments have been selected on a basis of their toxic properties which have been demonstrated in laboratory trials or small field tests. These materials come from different agencies, such as the United States Department of Agriculture, experiment stations, and chemical companies.

The Ohio Station conducted its first field tests of new materials at Wooster in 1925, when two types of manganese arsenate were tried in comparison with lead arsenate. The results were such as to warrant further trials the next season. During 1925 and 1926, field experimentation was in a rather crude form. Plots were laid out without replication and in several instances different varieties were included in different plots and later used in making comparisons. By the end of 1926, however, the fallacy of such work was clearly evident and since that time all materials have been replicated. This system has given far more consistent and dependable results. At first, plots of from nine to 12 trees were used, and these were replicated twice. Later, smaller plots, replicated more frequently, were employed, and this system is in use at the present time (1937).

It will be impossible to record in detail all of the experimental work performed during the 11-year period in which efforts have been under way to develop one or more satisfactory substitutes for lead arsenate. Of necessity, therefore, little more than a summarization of the results with each material or combination will be given.

Manganese arsenate.—As previously indicated, trials with this material were started in 1925, and different phases of its investigation were continued until 1935. During the first 2 years, the Experiment Station conducted the work but after that time it was financed by the Grasselli Chemical Company, although the Station cooperated in the tests. At the outset, manganese arsenate was used in all-season spray schedules and as the experiments were located in lightly infested areas, very little difference in control was noted between it and lead arsenate. When the problem of lead residues came to the front, manganese arsenate was tried as a substitute for lead arsenate in the late cover sprays, and again only small differences favored the lead. It was tried also throughout the season in a combination with lead arsenate in which half of the recommended amount of lead arsenate was replaced by manganese arsenate. Various sticking and spreading agents were used with it in the hope of increasing its efficiency. The results of the long series of experiments with manganese arsenate may be summarized in the statement that it is not as efficient as lead arsenate. Where infestations are low, no great difference between the two materials has been noted, but in areas where codling moth is severe the use of manganese arsenate has resulted in an appreciable increase of injured fruit.

Scorodite (a native iron arsenate).—This material was tested at Wooster and Marietta in 1927. The results were so unfavorable, both from the standpoint of spray injury and from its failure to control codling moth, that no further tests were conducted.

Tricalcium arsenate.—Tests with this material were conducted at Wooster and Marietta in 1927 and at Delaware in 1928. Fairly good control of worms was obtained but the injury to foliage was so severe that the material was dropped.

Aluminum arsenate.—A fair control of codling moth was secured with aluminum arsenate in tests at Wooster and Delaware conducted in 1928. However, injury to foliage was severe and of such a nature as to preclude the usefulness of this material in the orchard.

Magnesium arsenate.—Foliage of trees sprayed with this material was uninjured but tests conducted at Wooster in 1933 and 1934 indicated that injury by codling moth was almost unchecked. In fact, control was poorer with magnesium arsenate than with any other of the nonlead arsenicals.

Zinc arsenate.—This material was first used by the Ohio Experiment Station in 1927 at Marietta. The variety of apple was Rome. There was little injury to foliage and there was a fair degree of codling moth control. In tests repeated in 1928 at Delaware, Ohio, the control of insects was satisfactory but injury to foliage was severe. No tests of zinc arsenate were conducted in 1929 or 1930, but in 1931 a new "improved zinc arsenate" was obtained from the Rex Chemical Company. This material was used in many tests extending over a 4-year period. Also, a zinc arsenate produced by the General Chemical Company has been tested. Most of these trials have dealt with the possibility of using zinc arsenate during late June and throughout July as a substitute for lead arsenate. Zinc arsenate has been used alone, with stickers, at the strength usually recommended for lead arsenate, and in increased dosages. In all tests where it was used with 4 to 6 pounds of lime per 100 gallons of spray it has been safe to foliage. Like manganese, it is not as effective against codling moth as lead arsenate, but where the first brood of worms is well controlled it may be used in midsummer by increasing the dosage 33 to 50 per cent above that of lead arsenate. It may be used effectively against apple maggot also.

Calcium arsenate.—For many years calcium arsenate has been used sporadically as an orchard spray. Some growers have had fair success with it but in many instances poor control of insects and injury to fruit and foliage resulted from its use. Therefore, calcium arsenate was not included in our tests until 1931. Since that time it has been used each year in much the same manner as zinc arsenate. By substituting any nonlead arsenical for lead arsenate in late June and during July, the amounts of lead residue on the fruit at harvest time can be greatly reduced. The main question, of course, is, will the substitute arsenicals control codling moth and apple maggot equally as well as lead arsenate? None of the nonlead arsenicals, calcium arsenate included, are equal to lead arsenate in this respect when used at corresponding strengths. Tests have shown, however, that when the arsenates of calcium, zinc, and manganese are used in the midsummer sprays in quantities 30 to 50 per cent greater than the normal dosage of lead arsenate, their effectiveness approaches that of the latter. Therefore, in sections of the State where codling moth is not severe and in orchards where the first brood has been well controlled, these substitute arsenicals may be used in late sprays.

In dry seasons calcium arsenate has never produced injury but in the cool, wet season of 1935 considerable burning to foliage occurred. There has been no opportunity to try in the field the new "safe calcium arsenates" developed during the season of 1936.

Colloidal lead arsenate.—This material was tested at Delaware in 1926 and 1927. Results from the standpoint of insect control were very unsatisfactory.

Summer oil.—The first test of summer oil was conducted at Delaware in 1926 when a plot of Rome trees was sprayed throughout the season with Volck. This schedule was ineffective but the possibility of avoiding dangerous residues by the use of oil led to many other experiments. In 1927, 1928, and 1929 different summer oils were used following lead arsenate in the calyx spray. These schedules were more effective than that of 1926 but did not compare with lead arsenate used throughout the season. In 1930, 1931, and 1932, series of tests were conducted in which the effect of two applications of oil in midsummer was compared with that of one lead arsenate spray. Thirty-five tests were made in many different sections of Ohio in the 3 years. The summarized results are given in Table 7.

The results shown in Table 7 demonstrated very definitely the superiority of lead arsenate over the oils in midsummer, and further experiments of this type were abandoned.

Oil-lead arsenate.—(See mineral oil as a sticker for lead arsenate). Work with this combination has extended over an 8-year period with very favorable results in codling moth control.

TABLE 7.—Lead Arsenate versus Oils Applied in Midsummer

Year	Number of trials		Tie trials
	Favoring lead arsenate	Favoring oils	
1930	3	0	1
1931	18	1	5
1932	4	1	2
Totals	25	2	8

Oil-nicotine.—As early as 1931 it was indicated that oil alone was not a satisfactory substitute for lead arsenate in midsummer sprays. It was decided, therefore, to try to increase the toxicity of the oil by adding to it different forms of nicotine. Nicotine sulfate was selected as the most likely agent and several series of experiments were conducted with it from 1931 to 1935, inclusive. By these tests it was shown that 1 gallon of summer oil plus ¾ pint of nicotine sulfate per 100 gallons of water was the best all-round formula; that one spray at these strengths, substituted for one of lead arsenate in midsummer gave approximately the same results; and that two applications of oil-nicotine for one of lead generally gave better control. The disadvantage of this formula is its high cost.

In 1936 a chemically processed ground tobacco known as Ortho-Nicotine was used with a ready-mix oil at the rate of ½ per cent. When substituted in a five cover spray schedule for the last four covers it gave good results in codling moth control.

Nicotine-tannate.—In connection with the oil-nicotine work, a form of nicotine known as nicotine-tannate was tested. This is made by combining free nicotine with tannic acid in the spray tank. The result is a very fine precipitate in which the nicotine is held in a nonvolatile form. The tests were run over a 3-year period (1931-1933, inclusive) but because of poor worm control and the high cost of the materials, further work with this combination was abandoned.

Other nicotine forms.—Several commercial nicotines have been tested from year to year but at present none of them are recommended for use.

Potassium fluosilicate.—The results of 1 year's trial (1928) with this material were so unfavorable that further work was abandoned.

Barium fluosilicate.—In early trials (1928 and 1929) this material gave better results than potassium fluosilicate. In 1930 it was used with oil, which further increased its effectiveness. These tests were continued until 1934 but the material never achieved the effectiveness of lead arsenate and was finally dropped.

Natural cryolite (sodium aluminofluosilicate).—In 1931 this material used alone throughout the season was ineffective. In 1932, 1933, and 1934 when it was used with oil as a sticker and was applied as a substitute for lead arsenate in midsummer sprays, it was quite effective. It has generally given better results than any other fluorine compound. However, it leaves an objectionable spray residue and has, therefore, never been recommended for use against codling moth.

Synthetic cryolite.—Several synthetic cryolites have been tested from year to year but have never been as effective as the natural form.

Cuprous cyanide (Kutane).—This material gave very good results in the control of codling moth but in tests conducted in 1933 and 1934 it russeted fruit severely and also injured foliage.

TABLE 8.—Codling Moth Larvae per 100 Apples

Treatment	Ben Davis	Courtland	Jonathan	King David	McIntosh	Wealthy	Grimes	Golden Delicious	Arith. M.
11 A. Lead arsenate, 2 lb.-100 gal......... Flotation sulfur......................	27	23	9	17	....	10	7	5	14
10 A. Phenothiazine, 3 lb.-100 gal.......... Flotation sulfur...............	82	43	42	37	20	3	20	30	34
9 A. Phenothiazine, 3 lb.-100 gal...........	84	52	32	....	15	6	24	30	35
8 A. Oil (Orthol Ready Mix), ½% .... Ortho-Nicotine, 4 lb.-100 gal........ Coposil............................	82	39	18	29	....	6	7	15	28
7 A. Lead arsenate, 2 lb.-100 gal......... Dry lime-sulfur.............. .... (3 covers only)	52	36	7	12	4	1	3	9	15

Phenothiazine.—Phenothiazine was substituted for lead arsenate in the last cover spray in a midsummer schedule in 1935. Results were about the same as with lead arsenate, and as the material leaves no harmful residue, this led to considerable work in 1936. It was used alone and with flotation sulfur as a fungicide throughout the season and was compared with lead arsenate and Ortho-Nicotine schedules of the same length. Eight standard varieties were sprayed with each material; each variety was represented by two or more replicated one-tree plots. The results of this all-season test (calyx and four covers), expressed in terms of worms per 100 apples, are given in Table 8. All figures are summarizations for all replicates in each variety.

No more than a casual study of Table 8 shows that an all-season schedule of Phenothiazine was ineffective in codling moth control.

In other tests in which lead arsenate was used in the early-season cover sprays and Phenothiazine was substituted for the late cover sprays, the results were much more favorable but were not as satisfactory as those obtained from a complete lead arsenate schedule.

THE BASIS USED FOR EVALUATING LEAD ARSENATE SUBSTITUTES

The foregoing summarization of the several materials that have been evaluated as possible substitutes for lead arsenate does not convey an adequate impression of the volume of experimental work that has been necessary in order to make possible the conclusions that have been stated. In view of these facts, it seems desirable to mention briefly the general plan of experimentation that has been followed.

All evaluations have been based upon data secured from actual field experimentation, and, as has been stated previously, sufficiently numerous plot replicates have been utilized to yield reliable results. Power sprayers were used in all the work in order to conform to standard commercial orchard practices, and careful attention has been given to such details as thorough coverage, proper timing of sprays, and the examination of adequate quantities of fruit for evaluating the performance of each material under test.

An examination of the data obtained in a typical test of the type under consideration will serve as a demonstration. (See Table 9). These results

TABLE 9.—A Typical Example of an Experiment for the Evaluation of Lead Arsenate Substitutes in Codling Moth Control

Materials	No. of apples	Worms per 100	Lead residue*
1935			
Lead arsenate	39,774	3.1	0.047
Lead arsenate-oil	46,475	1.1	0.064
Zinc arsenate-oil	40,677	1.5	0.025
Natural cryolite-oil	41,383	2.4	0.027
Cuprous cyanide-oil	39,366	1.7	0.012
1936			
Lead arsenate	12,887	10.3	0.038
Zinc arsenate	13,894	12.2	0.019
Ortho-Nicotine-oil	10,234	6.8	0.010

*Grains per pound of fruit.

were taken from an orchard at Gypsum, Ohio, after the use of a schedule of calyx and five cover sprays. All figures are summarizations from series of replicated plots, usually five or 10 in number. All materials listed in Table 9 were substituted for lead arsenate in late cover or midsummer sprays only.

This table illustrates very well the point that control of worms may be obtained by substitutes whose effectiveness is increased by stickers (i. e., oil). However, the fact will also have been noted that lead arsenate – oil was the most effective.

SUPPLEMENTARY CONTROL MEASURES

LIGHT TRAPS

On account of the cost of an experimental installation of lights and also because the cost of installation and operation makes their commercial use of doubtful practicability, even if control were obtained, the Ohio Station has not conducted experimental work with this method of control.

ORCHARD SANITATION

In an early section of this bulletin are listed the many different operations which may be classified as sanitary practices. During the several years of the codling moth investigation it has been the custom while visiting orchards to take notes on sanitary conditions and to attempt to correlate these with existing codling moth infestations. From these observations it has been learned that possibly one or two sanitary practices may be neglected without serious consequences but that if neglect is general it is always evinced by increased codling moth injury. These findings, in connection with the results of sanitary experiments in Indiana and Illinois, show definitely that orchard sanitation has a place in the control program.

BAIT PAILS

Observations of the use of bait pails in Ohio lead to only one conclusion, namely, that this is not a practical method of control at the present time. In southern and central Ohio, however, they are quite valuable in determining moth activity, which governs the proper timing of sprays.

BANDING

This is the oldest method of control and has been recommended for more than 100 years. However, with the advent of spraying as a suppressive measure, banding was forced into the background for a period of nearly 30 years, or until the self-working or poison band was developed. This development took place from 1926 to 1930, and since the latter date such bands have had considerable commercial use. They are quite effective, especially against first-brood larvae, and usually will kill from 96 to 99 per cent of such larvae entering the band. Poison bands may be prepared at home or purchased ready for use. Trees that are to be banded should always be scraped; otherwise, many larvae will go under the bark instead of coming to the band for cocooning. Bands should be placed on the tree before the first larvae leave the fruit and should be removed and destroyed soon after harvest but not before the dropped fruits have been collected.

Experiments with bands from 1927 to 1930 dealt mostly with the selection of a band that would kill high percentages of the larvae that cocooned in it. After the testing of numerous materials it was decided that the beta-naphthol band, as developed by entomologists of the United States Department of Agriculture, was most efficient, and it was recommended for use in orchards where the degree of infestation required it.

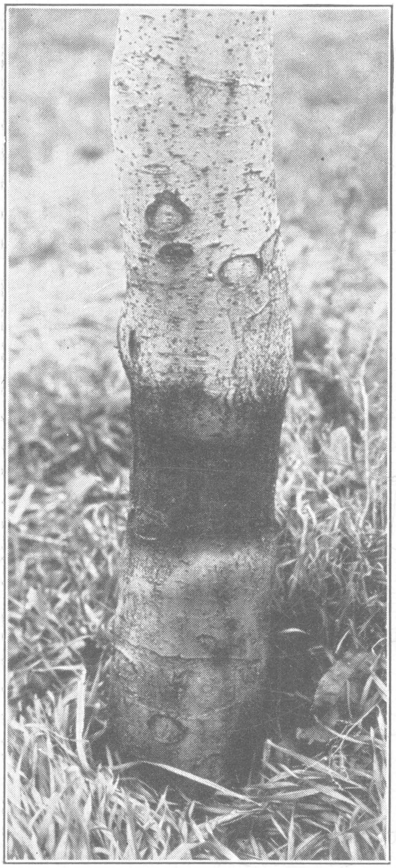

Fig. 19.—Injury to young tree trunk caused by beta-naphthol band applied in June, 1936. Photographed December, 1936

Other tests have shown that about 50 per cent of the worms may be expected to reach the bands after leaving the fruit. The other larvae will find cocooning quarters elsewhere or will be destroyed by weather, ants, toads, or birds. The exact percentage of larvae finding safe cocooning quarters is not known. Whether this number will be large enough to offset the number caught in the band and how severe the infestation in the orchard should be before bands are used are important questions. Experiments in banding large blocks of trees in orchards at Wooster, Marietta, and Gypsum and in Lawrence County, supplemented by observations of banding in large commercial orchards, have shown certain facts on which we can base an answer to the foregoing questions. These are: (a) Banding is entirely a supplementary control and will not replace spraying. In short spray schedules banding will not take the place of a single spray application. (b) Where five or six cover sprays will control codling moth, banding should not be used. (c) When the number of cover sprays necessary to control is greater than five or six, banding becomes economically practicable. (d) Banding is most efficient when used in connection with a complete program of orchard sanitation and with a well-timed, thorough spray program. (e) Never band young trees (Fig. 19).

SUMMARY

Since the text of this bulletin is in itself a summary of over 10 years' work with the codling moth, there will be no attempt to present details in this section. Rather, it is hoped that some principles fundamental to codling moth biology and control may be pointed out.

1. The destructive activities of the codling moth are greatly influenced by weather conditions.
2. Temperatures below the mean during late May and throughout June greatly aid in the control of the insect during that season.
3. When temperatures are above normal during May and June, a serious outbreak is to be anticipated because eggs hatch in a shorter time and larvae leave the apples earlier, thus permitting a larger proportion to transform to moths in the midsummer broods.
4. The increased hazard from codling moth due to warm seasons may be offset by extra sprays applied after the calyx. Such sprays are designed to build up residues and poison early larvae. Bands applied before the first larvae leave the fruit are of value because they also decrease the number of midsummer-brood moths and larvae.
5. Moth emergence under natural conditions in the orchard extends over a longer period and is characterized by lower peaks than the emergence from cages.
6. For commercial control in severely infested sections the tree must receive an adequate amount of spray. The minimum amount per application is usually considered to be ¾ gallon for each year of the tree's age.
7. Spray must be so applied to the tree that all surfaces of fruit and foliage are covered.
8. From the standpoint of cost and efficiency, lead arsenate is still the best orchard insecticide. It should never be omitted in the calyx spray. However, the use of lead arsenate after the second cover spray will almost surely produce excess spray residues.
9. Nonlead arsenicals (calcium, zinc, and others) are less effective than lead arsenate and their use in all-season schedules is not recommended. However, in orchards where insects are well controlled they may be used in late-season sprays at 1½ times the usual strength of lead arsenate, provided excess lime is added. In their present forms they are not as safe as lead arsenate.
10. Natural cryolite (the best of the fluorine sprays), when used with summer oil, is fairly effective against codling moth but its use after the second cover spray also gives excess residues.
11. Nicotine in its various forms, if applied frequently, is effective against codling moth but not against apple maggot. It is more expensive than lead arsenate.
12. Phenothiazine has shown promise as a control for codling moth in the Pacific Northwest but experiments in Ohio and elsewhere in the East show that in its present form it is not suited to eastern conditions.
13. The use of recognized sanitary practices is to be considered when a spray schedule of more than five cover sprays is necessary to control codling moth.
14. Satisfactory control under conditions of heavy infestation is more nearly assured if, in addition to spraying, all supplementary sanitary practices are employed rather than only one or two.